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METALLURGIA

THE BRITISH JOURNAL OF METALS

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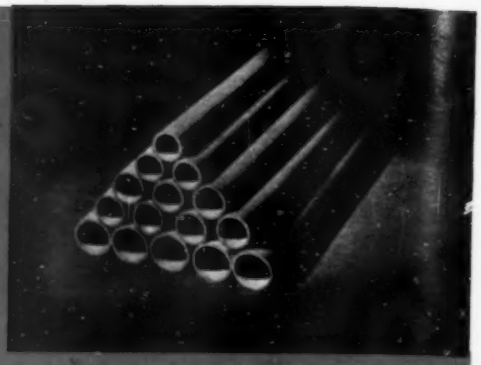

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METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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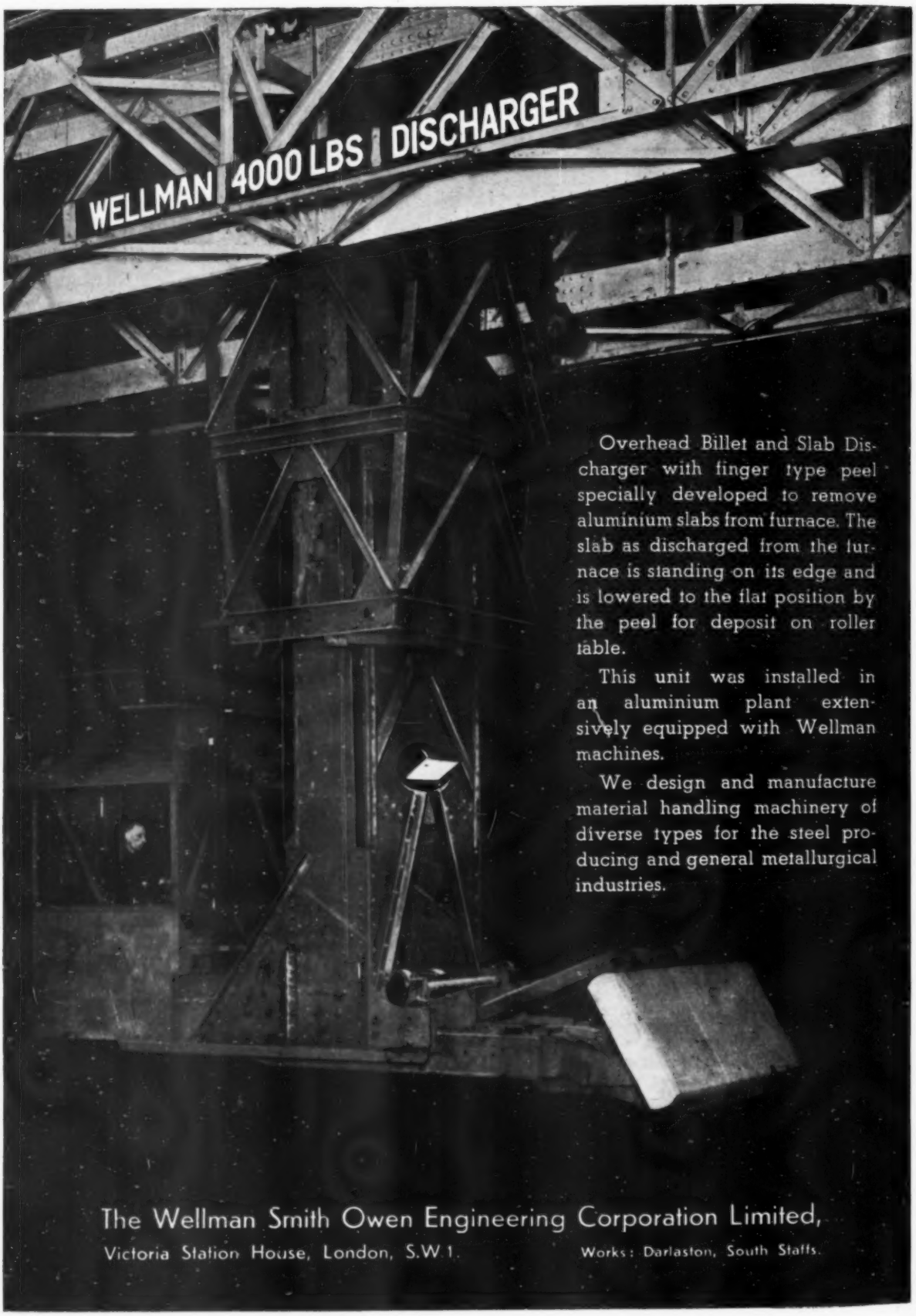

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METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

JUNE, 1947 Vol. XXXVI No. 212

Oxygen in Metallurgical Work

USES of oxygen, like those of hydrogen, have increased considerably in recent years, and will in all probability continue to do so on an ever augmenting scale, especially where a very high standard of purity is not required, and it can, therefore, be produced at relatively low cost. This would be particularly the case in extractive metallurgy—e.g., in blast-furnace practice; and its use here should be the more valuable under present conditions, owing to economy of fuel. More generally it may be said that some of its principal and potential applications are either as oxygen or oxygen-enriched air[1]:

1. Production of gas from coal by continuous and complete gasification, probably with increased thermal content.
2. Production of gas suitable for hydrocarbon synthesis, etc.
3. Oxidation of ammonia and sulphur dioxide, and for partial oxidation of organic compounds.
4. Roasting and burning of sulphide ores, pyrites and other sulphur-containing compounds.
5. Smelting iron ores and refining.
6. Combustion of fuels.
7. Flame-surfacing of metals.
8. Cutting and welding metals, etc.

Many other uses would no doubt present-themselves if and when the cost of oxygen is sufficiently low.

In the metallurgical field the roasting of sulphide ores, for example, has been greatly facilitated by the use of oxygen-enriched air, so that sulphur dioxide concentrations in the flue gases can be raised to 7% or more; that is, to a degree where recovery becomes a much more feasible proposition. And it is not necessary, of course, in such cases to supply gaseous, liquid, or solid fuel to maintain combustion and working temperatures. Thus, too, smaller plant and equipment can be used. Similarly in ore reduction in blast furnaces it is possible to increase concentration of carbon monoxide—the chief reducing agent—by using oxygen which considerably raises the temperature and favours dissociation of carbon dioxide, with consequent increasing concentration of carbon monoxide. Control of this latter and of temperature may thus be achieved through regulation of the oxygen supply. Other well-known advantages include increase in flame temperatures, so that combustion time and size of plant are reduced. and here again better control can be effected.

The literature of oxygen production and its manifold uses is naturally very extensive. Some of this is reviewed in the light of recent developments in Germany and the U.S.A. by Downs and Rushton;[1] and production of oxygen for industrial purposes is described in more detail, with special reference to the new Kellogg low-pressure process, by W. E. Lobo,[2] and by Rushton and Stevenson.[3] These authors give the following table of approximate costs of plant and per ton of oxygen, using apparently the air liquefaction and rectifying plant, based on German practice with certain modifications, to produce 95% oxygen: —

Plant capacity, tons/day	120	240	360	480	1,080
Cu. ft. in mill./day	2·88	5·76	8·64	10·52	24·00
Approx. cost of plant in mill. doll.	0·9	1·3	1·7	2·0	3·4
Total operating cost/ton in doll. ..	5·21	3·95	3·52	3·19	2·75

In the first of the papers cited some information is given on the production of gas from coal or lignite by the oxygen enrichment method, such as that of Lurgi in Germany and Czechoslovakia. In the last-named country it is reported that the latest Lurgi installation at Möst is producing about 15 mill. cu. ft. of B.th.u. city gas per day. It is thought that gas up to 900 B.th.u. could be made at thermal efficiencies of 80%. Some account is also given of the Winkler method for city gas production, synthesis gas, and the Synthine method for liquid fuel production.

The use of oxygen or oxygen-enriched air in connection with sulphuric acid and sulphur dioxide production—e.g., in pyritic ore roasting, is discussed by Downs and Rushton at some length, with special reference to recent work in the U.S.A. In that country, as elsewhere, large amounts of pyrites, as ores and concentrates from copper, zinc and gold mining, are at present not being used, and the same applies to iron pyrites tailings. It is suggested that some way should be found of adopting oxygen enrichment to deal with these. As the pressure of demand on existing sources of metal supplies, especially iron, becomes greater it will be necessary to resort to these at present uneconomic sources of supply. In this connection the use of oxygen will be a dominant factor, and no doubt hydro-electric power would be another.

It is doubtless appreciated by now that, as a general rule, the use of oxygen-enriched air for non-ferrous ore reduction is an attractive proposition, and more especially in the smelting of copper, nickel, zinc and lead ores; and offers many advantages from the higher temperatures attainable, increased reaction rate, and use of fluxes to form higher melting point slags. This latter possibility includes the use of new and better fluxing materials, with consequent improved control and improved metal yield. Recent research has been directed to the use of oxygen-enriched air on fluidised low-grade sulphide ores—e.g., in Herreschoff burners. By way of example, the work of the Consolidated Smelting & Refining Co., of Canada, Trail, B.C., may be cited. They have, during the past few years, used oxygen enrichment for roasting zinc sulphide concentrates. The roasted concentrate produced is zinc oxide mixed with gangue.

1 *Chem. Eng'g. Progress*, 1947, 1, 12–20 (Janr.).

2 *loc. cit.*, 21–6.

3 *loc. cit.*, Feb., 61–6.

Usually roasted concentrates average about 65% zinc oxide, and are smelted electrically to produce zinc vapour. The Herreschoff furnaces normally have been supplied with air and natural gas. By adoption of oxygen-enrichment, however, the natural gas could be eliminated, the total gas volume reduced, and higher temperatures and yields made possible. Since, in North America, more than one million tons of zinc are produced annually, this alone would be a large potential field for oxygen: and much the same applies to lead ores.

In the iron and steel industry oxygen has long been used for cutting, welding, scarfing and, more recently, for flame treating surfaces; but in such cases relatively high purity is demanded—up to 99·5%. This, too, has involved the development of mobile units for use in individual plants, the necessary equipment often being hired or leased. But the cost of such oxygen may be ten times as much as that of the 95–97% grade made in large plants. Oxygen offers great advantages in the operation of pig iron blast furnaces, Bessemer converters, and open hearths. Much of the early work on the use of oxygen in this way was done in Germany with oxygen produced by the Linde-Frankl process. Only comparatively small enrichment was employed—namely, from 21%—the normal air content—up to 26%, an enrichment of only 5%. This required no changes in furnace structure or refractories. But higher enrichments, up to 30%, were used in the ferro-manganese blast furnaces.

The possibilities in this direction in the U.S.A. are said to be considerable. A survey made in 1946 showed that there were 255 pig iron blast furnaces in the U.S.A., and if all of these were equipped with apparatus to make 95% oxygen and enrich the blast up to 26%, no less than 900,000 cu. ft./min. would be required, or rather more than 2,200 tons per hour. It is, of course, hardly likely that all of them would be so equipped, but even a relatively few would consume large amounts of oxygen, even with such small increase above normal oxygen content as 5%. This could be increased, possibly up to 30%, with little change in furnace design. Oxygen plants for use with steel operations are being built in the U.S.A. and its consumption in this field may run into large tonnages. Some further research on refractories and on furnace design would, however, be needed.

Work in this line in Russia has been referred to by Bardin[4], who states that oxygen has been used on a large scale in the Dnepropetrovsk plant since 1940–41, with a blast furnace of 217 cu. m. Here ferro-silicon was smelted with oxygen in the blast not over 32%, preheated to 700°. It is said that production was practically doubled and that expenditure in coke per ton was 25% less than with ordinary air blast. Itemised estimates are given of cost, including man-power requirements—much lower with oxygen process—and capital invested, resulting in an annual saving of 171 million roubles on a 10 million ton pig iron production. Langmuir,[5] in a report of his visit to Russia in 1945, refers to further work.

A new Russian journal *Kislorod* (Oxygen), first published in 1944, described some recent progress not only in connection with blast furnaces, but also with Bessemer converters, open-hearth furnaces, and other metallurgical work. It included more particularly:—

1. Design of open-hearth furnaces for use of oxygen-enriched air.
2. Production of ferro-chrome containing 50–60% chromium in blast furnaces using air enriched to 30–40%, in regard to which it is claimed that coke consumption is two-thirds to one-half that required in the ordinary blast furnace, and energy requirements are only about 22% of electric furnace consumption.
3. Use of oxygen in Bessemer converters which would, among other things, eliminate danger of steel being saturated with nitrogen and hydrogen, facilitate treatment of pig iron regardless of phosphorus content, shorten cycle of operations, and permit use of 25% scrap. Some revision of converter design would, however, be necessary.

W. E. Lobo (of M. W. Kellogg Co.) describes an improved oxygen plant based to some extent on German practice and developed by the Nat. Defense Research Committee. Briefly, the process is as follows: Filtered air is compressed in a two-stage oil-free compressor, of 77 lb./sq. in., and while still hot is passed through a catalytic oxidation chamber where traces of hydrocarbons, especially acetylene, are converted to carbon dioxide and water. The air is then cooled before passing to the water separator and to the automatic three-way reverse valves which guide it alternately to first one and then to the other of the two reverse passages of the main or reverse exchanger. This exchanger is based on a principle suggested by Prof. S. C. Collins, of the Massachusetts Inst. of Technology. It both cools and further purifies the air. The high pressure compressor aftercooler is usually saturated with water under the prevailing conditions of about 90° F. and 77 lb./sq. in. and contains about 0·03% of carbon dioxide. As this air is cooled it progressively deposits first liquid water, then ice, and finally carbon dioxide snow. If the air is cooled sufficiently the remaining concentration of these impurities will cause no operating difficulties over a long period, provided the exchanger heat transfer surface does not become foul. To eliminate such fouling is the purpose of the reversing feature of the exchanger. The foregoing gives briefly some idea of the principle on which is based the Kellogg new low pressure oxygen process, and the unique "temperature unbalance system." Cost of the plant is said to be reasonable, and permits of low cost oxygen production on a large scale—e.g., 15 cents/1,000 cu. ft. for 350 ton/day plant.

It has only been possible to refer very briefly to some of the work done in applying oxygen to various industries, but it is noteworthy that at the recent annual meeting of the British Oxygen Company the Chairman announced that the Company is co-operating in the research work involved in the use of low-purity oxygen for development of the coal, steel, oil and chemical industries. There seems little doubt that there is a big field for the possible use of low-purity oxygen in this country, and, under present conditions of fuel shortage, it would seem that big-scale developments of this kind would assist these industries in no small measure.

4 Bardin, I. P., *Bull. acad. Sci., U.S.S.R.* 1946, 1385–99.
5 *Chem. Eng. News*, 1946, 24, 759.

Forthcoming Meetings

THE IRON AND STEEL INSTITUTE has made arrangements to hold a Summer Meeting in Switzerland next month.

The Institute of British Foundrymen will hold the Annual General Meeting for 1947 in Nottingham on June 17th–20th.

Some Technical Aspects of Oil-firing Industrial Furnaces

By G. Reginald Bashforth, F.I.M.

The use of oil fuel for firing industrial furnaces is not new in this country, it is only recently, however, that oil has been introduced for open hearth furnaces. A number of such furnaces are now operating on oil while several are in the process of conversion to oil-firing. Oil is probably the cheapest form of easily controlled fuel, but, to obtain the maximum efficiency from its use, the conditions of combustion must be very carefully controlled, and the technical aspects of oil-firing discussed in this article will assist toward a better understanding of these conditions. Attention is directed to the characteristics and properties of fuel oil, its advantages and disadvantages, storage and supply lines, atomisation, burner and burner design, and the importance of control instruments. Brief reference is also made to the use of tar and tar oils.

RECENTLY, partly due to inadequate supplies of coal, many industrial plants have adopted oil as a means of heating their furnaces. In several cases much greater economy and efficiency has been attained. In view of this fact, the employment of oil may become the established practice for the future. The success of this method of heating, however, depends to a large extent on the manner of installation and the degree to which combustion and furnace operation can be controlled. Great efficiency has been achieved at those plants where instruments have been introduced to assist this control.

Reference is frequently made erroneously to "crude oil," but this is not used for industrial purposes. Crude oil is the liquid which issues from the earth, and is refined before application. In the course of refining this crude oil yields petrol, paraffin oil, gas and diesel oils, and lubricating oils. The residue resulting from this distillation consists of heavy oils and bitumen. It is these heavy oils, generally referred to as "residual oils" which are normally used for industrial heating.

Characteristics and Properties of Fuel Oil

The chief characteristics and properties of oil, which influence its industrial application and affect its adoption in metallurgical processes, may be enumerated as follows :—

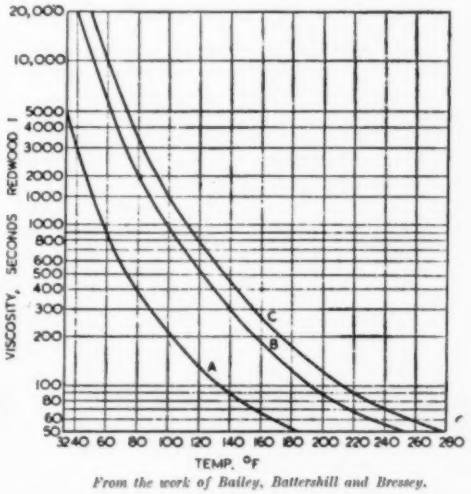
Calorific Value, which can be determined by the "bomb calorimeter," is obviously of importance, as it indicates the thermal value of the oil in question.

Specific Gravity, which can be determined by the hydrometer, the specific gravity balance or the specific gravity bottle, appears to affect ignition and flame velocity, although some difference of opinion exists on this point. In general, heavier oils burn more slowly than lighter oils. Most authorities contend that specific gravity influences ignition velocity, but ignition velocity is affected by preheat and turbulence. Some adjustment to atomisation and burner design may, however, be necessary to meet wide variation in specific gravity.

Flash Point, that is the temperature at which, on being slowly heated, the oil evolves sufficient vapour that on the application of a flame or spark produces a momentary flash. The flash point indicates the tendency for the oil to catch fire, and is therefore, of importance from a storage aspect. If the flash point is over the regulation minimum of 150° F. it can be stored and handled under proper conditions without serious hazards of fire.

Carbon Content, which affects the degree of luminosity of the flame, is of interest. The higher the carbon content, the higher the luminosity and thereby the radiating power of the flame.

Sulphur Content, which in some oils is considerable, may have an adverse effect in many metallurgical processes.



(a) Pool fuel oils.
(b) Pool heavy fuel oil.
(c) A 1,500 secs. fuel oil.

From the work of Bailey, Battershill and Bressey.

Fig. 1.—Typical viscosity curves of fuel oils.

Ash Content of certain oils may be appreciable and may affect metallurgical processes. In some cases heavy deposits have resulted in the regenerators of regenerative furnaces when oils possessing high ash contents have been employed. At some works using oils with very high ash contents, it has been found necessary to clean the top of the checkers with compressed air once a month. At other works these difficulties have been overcome by opening up the spaces or flues in the checker brickwork. Normally, the ash content should not be sufficiently high to produce serious trouble in this respect.

Viscosity is undoubtedly the most important characteristic. This property may be measured in several ways but the usual method is to record in seconds the time taken for a given quantity of the oil to pass through a standard orifice or short pipe under standard temperature conditions. In England, the Redwood No. 1 viscometer is usually employed, and the time taken quoted in seconds.

When comparing oils, their viscosity at 100° F. is generally considered. This viscosity, of course, is readily affected by temperature and the influence on the viscosity of three typical fuel oils is shown in Figure 1, taken from the work of Bailey and others.[1]

The viscosity of oils at varying temperatures is important from both a pumping, circulating and atomising aspect. When there is a possibility of having to employ different grades of oil, it is desirable to have a chart showing the viscosities of the oils at various temperatures, so that rapid adjustments can be made when exchanging from one oil to another. The existence of a viscosity chart of this type enables rapid changes to be made to the preheating of the oil to ensure free pump circulation or satisfactory atomisation.

Advantages and Disadvantages of Fuel Oil

One of the great advantages of the use of fuel oil is the ease with which it can be transported, handled and applied. At plants situated by the sea or large rivers, ocean going tankers may be employed for transporting the oil. The oil can be pumped direct from tankers into storage tanks at the works. When canals are available, specially constructed barges may be used.

In most cases, however, rail-car tankers are employed for transporting the oil from the depots or refineries to the plants at which it is being applied. These tank-cars are usually provided with steam coil heaters, so that the oil may be heated if necessary to assist its transfer to the storage tanks. The actual amount of preheat required, will of course, depend on the viscosity of the oil being handled. It is frequently advisable to preheat to avoid deposits of heavier material being left in the tank-cars.

Although the cost of this storage and supply system is expensive, the capital cost involved is considerably lower than the cost of a producer gas plant required to meet the same thermal demand.

A high thermal efficiency can also be obtained. When oil is employed approximately 95% of the heat units in the oil are delivered to the furnace. If coal is converted into producer gas, even with good producer practice, only about 70% of the heat units are delivered to the furnace. This percentage may be less, depending on the actual producer practice, the length of the gas mains and the amount of sensible heat in the gas that can be utilised.

Interruptions due to tar and dust deposition, which are frequently attendant to producer gas practice, are prevented by the application of oil-firing. This point is of considerable economic importance in many works.

When supplies of blast furnace and/or coke oven gas are available, the economics of oil-firing become less attractive. These gases, however, owing to the lack of luminosity, which reduces their radiating power, are not ideal fuels for many industrial furnaces. It is obvious, therefore, when other more suitable and profitable applications can be found for these by-product gases, oil-firing again becomes attractive.

There is every indication that a much greater accuracy of combustion control can be obtained with oil than with other types of fuel. On open hearth furnaces in America, it is claimed that the use of oil has led to increased production rates and a much more precise control of metallurgical processes.

The cost of the oil, however, assuming no greater thermal efficiency is obtained, must be considered against these advantages.

Storage and Supply Lines

Ample storage capacity is of paramount importance. A storage capacity of at least 7 to 10 days consumption is generally advocated. In view of the fact that this country depends on imported fuel oil, a larger capacity equivalent to 14 to 21 days consumption is recommended. This capacity will help to assure continuity of operation against the unavoidable delays which must occur with seaborne traffic from time to time.

Some engineers advocate the employment of large storage tanks, whilst others prefer small units giving the same total capacity. Large units may be less expensive to erect and maintain, but a series of smaller tanks are an advantage when varying grades of oil may have to be employed.

These storage tanks are generally heated by means of a steam coil, which should be situated as near as possible to the oil outlet. In some cases, electric immersion heaters are preferred to the steam coil type. At plants where steam is not used for atomisation, electric heaters are of course, an advantage. In either case, these heaters should be thermostatically controlled to assure a regular temperature. The thermostat is normally located in the pipe leading from the storage tanks to the pumps.

The temperature to which the oil is heated at this point will depend on the type of oil used. The preheat is necessary to lower the viscosity sufficiently to allow free pump circulation.

A kinematic viscosity of 12·5 stokes (that is, about 5,000 secs. Redwood 1) represents the maximum practical conditions for pumping. For free pump circulation, however, a kinematic viscosity of 3·5 stokes, which is equivalent to about 1,500 secs. Redwood 1, is to be recommended. It is advisable for each plant to determine by experiment the most suitable conditions of circulation and then to standardise those conditions according to the type of oil being employed.

At some plants gravity feed is adopted. In this method the oil flows by gravity from an overhead tank to the burner. Gravity feed is not recommended, except for small plants.

In large installations the oil is pumped from the storage tanks through ring mains to the burners. The pumps employed should be of the positive displacement type and should be placed as near the storage tanks as possible. It is advisable to provide air vessels of adequate size to absorb the pulsations of the pump operation, as irregular pulsations in the oil-flow are reflected in the flame developed in the furnace. Pumps should be duplicated to avoid stoppage in case of pump failures and to allow the cleaning of the system.

Normally, the ring main is built up of two pipes, one forming the oil-flow pipe and the other the return pipe to the suction pump and/or storage tank. This

1 Bailey, Battershill and Bressey. *Trans. Inst. Petroleum*, 1946.

method ensures a constant flow of oil and permits short branch pipes being led off to individual burners as required. The ring main should be placed as near to the individual burners as possible, thereby reducing the length of the branch pipes to a minimum. In the case of long ring mains, a steam tracer pipe to maintain the oil temperature is necessary. (See Fig. 2.)

It is important that the oil main is properly dimensioned. The actual size of the ring main employed will depend on the quantity of oil to be circulated, the viscosity of the oil at the circulation temperature, and the length of the main. As a general rule such mains will be not less than 1-in. bore, whilst for a unit consuming 600 gals. per hour a 2-in. ring main will be necessary. For a large installation, a 4-in. ring main, with a 1-in. diameter tracer pipe may be necessary.

In order to maintain the temperature during circulation, the two oil pipes and the steam tracer pipe should be lagged together. One inch thickness of 85% magnesia insulation should give satisfactory results.

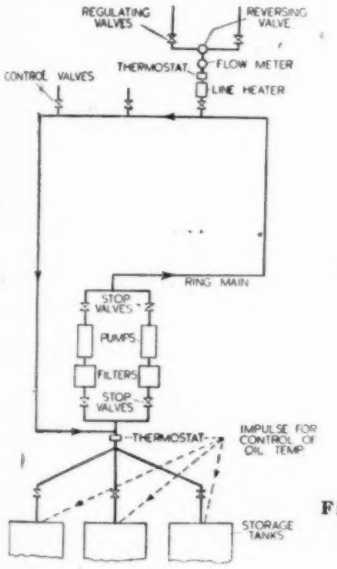


Fig. 2.—An oil flow diagram.

One feature of considerable importance in the successful application of oil-firing is adequate filtration, which is carried out normally at two stages. The coarse material, which might interfere with pump operation or free circulation is removed by a coarse filter situated between the storage tanks and the pumps. This filter will vary up to 20 meshes per linear inch.

A finer filter is generally employed at a point prior to atomisation. This filter may vary according to the type of atomiser used, up to 100 meshes per linear inch.

These filters should be easily accessible to facilitate cleaning and should be duplicated to prevent stoppage during the process of cleaning. The filter gauges are usually made of a corrosion-resisting material, such as monel metal or phosphor bronze.

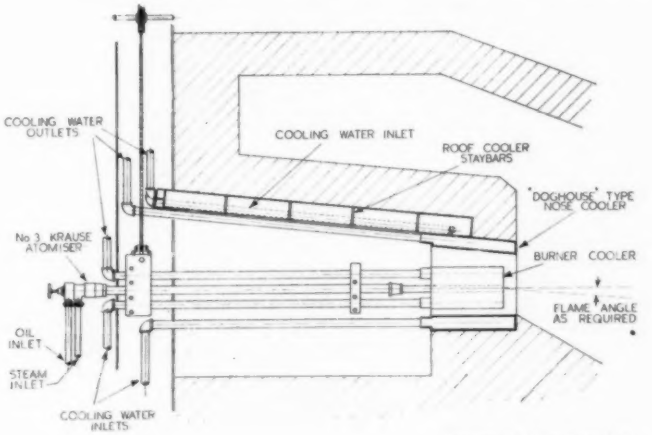
According to Hudson, Bressey and Bailey,[2] all joints should be packed with compressed cork, cardboard or asbestos-coated with an oil-resisting compound. They point out that jointing containing rubber should not be used. Discussing materials for use in the manufacture of heaters, they state that brass, lead or galvanised metal should not be employed.

A considerable amount of water is likely to settle out of the oil, therefore all storage tanks and oil mains should be provided with adequate drain cocks. Drain cocks should also be provided for draining oil from the system during prolonged stoppages.

Normally, control valves are provided between the storage tanks and the pumps, and between the pumps and the ring main so that either set of pumps and heaters can be readily isolated if required. Control valves are also provided at each branch pipe, so that individual installations can be isolated.

Atomisation

Atomisation depends on breaking the oil stream up into a fine spray or mist of oil particles, each of which is capable of intimate contact with the air necessary for combustion. It is, therefore, obvious that the finer the spray, the more intimate will be the fuel/air



Courtesy of Blaw-Knox Ltd

Fig. 3.—Typical arrangement of burner and coolers for open hearth oil-firing furnace.

contact and the more rapid the combustion. The more rapid the combustion the shorter will be the flame. This factor is employed in the open hearth process to vary the type of flame during the various stages of operation. When charging and melting down the raw materials, during which a short intense cutting flame is desired, a steam pressure of 100 to 120 lbs. per sq. inch may be employed. This steam pressure may be reduced to 80 to 100 lbs. per sq. inch during the carbon boil and refining operations, when a long, luminous flame is more beneficial.

In order to obtain satisfactory atomisation, it is important that the oil is at the correct degree of viscosity. The actual temperature to which the oil must be preheated to give this requisite viscosity depends on the type or grade of oil being used.

Some authorities maintain that a kinematic viscosity of 0·25 stokes, which is equivalent to about 100 secs. Redwood 1, is a satisfactory condition for open hearth and many similar types of furnace. At several open hearth plants satisfactory atomisation and flame conditions are being obtained with a viscosity of approximately 300 secs. Redwood 1.

In America, when using Bunker C fuel oil on open

[2] Hudson, Bressey and Bailey. *Inst. Fuel*, 1940.

hearth furnaces, the oil is preheated to 160° to 180° F. prior to atomisation. If lighter, or less viscous oils are employed, this temperature is decreased. The actual temperature will also be influenced by atomiser and burner design. No hard and fast rule can be made, therefore, regarding the viscosity and/or temperature of the oil prior to atomisation. The degree of viscosity and/or the temperature of the oil best suited for each individual furnace or installation must be determined on site and then conditions should be standardised. When necessary to change from one grade of oil to another, reference to the viscosity chart for the two oils, permit rapid temperature adjustments to be made to meet the new conditions.

Overheating of the oil must be avoided, as this causes coking and vaporisation. Great care is frequently necessary to avoid overheating on the suction side of pumps which have a considerable suction left.

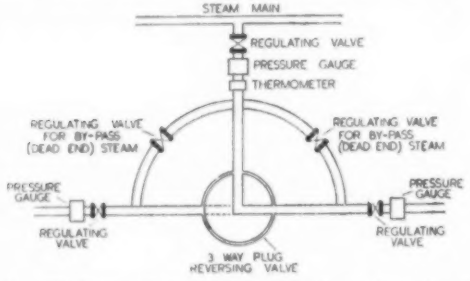


Fig. 6.—Diagram showing flow of steam for atomising.

Atomisation can be attained by three methods—a pressure jet, an air jet, or a steam jet system. In the pressure jet type of atomiser, the oil is forced at a high pressure through a specially designed orifice, from which it issues as a fine spray, having the form of a hollow cone. This system is not normally used for industrial furnaces. Its chief application is in connection with boiler firing.

High, medium and low pressure air jet systems have a limited application on the industrial furnaces. In some cases the air is supplied at a pressure of 1·5 to 2·0 atmospheres, when approximately 10% to 20% of the total air required for the combustion of the oil is introduced for atomisation. The remaining 80% to 90% of the requisite air can be preheated, thereby rendering possible the attainment of the maximum flame temperature.

Probably, the chief use of air jet systems is confined to those plants where steam is not available. In such cases the oil is heated for circulation and atomisation by electric heaters.

For high temperature installations atomisation is generally carried out with steam. This steam should be superheated. The chief disadvantage associated with the use of steam as an atomising agent is the lowering of the flame temperature, due to the presence of moisture. There is also the possibility of the water-gas reaction :—

$$H_2O + C \rightleftharpoons H_2 + CO$$

reducing the luminosity of the flame, thereby lowering the heat transfer by radiation. In spite of these apparent demerits, steam is the atomising agent most favoured.

Several types of steam jet atomisers have been employed successfully in connection with industrial furnaces. The oil flow may be surrounded by a high pressure steam jet, whilst in other designs a high pressure steam jet is encircled by the oil inlet. In open hearth furnace practice and some other industrial installations, perfect atomisation does not appear to be a fundamental consideration. A simply designed and constructed atomiser, capable of giving reasonably good atomisation, appears to produce a flame of the desired length and character, better than many of the more complicated systems, although those systems may give more perfect atomisation.

Burner and Furnace Design

There are several designs of burners which can be readily adopted to many industrial furnaces without much structural alteration to the furnaces. In the case of reheating and the smaller types of metal melting furnaces, the atomiser and burner tip or nozzle form a complete fitment, which can replace the existing gas or pulverised coal burners.

The most important feature appears to be the selection of a burner which will give the correct length and type of flame. As already pointed out, however, this is not only a function of burner or atomiser design, but is influenced by the pressure of air or steam used for atomisation.

In certain types of reheating furnaces the angle of the burner is of considerable importance. Some designers insert baffle walls or similar refractory structures to prevent direct impingement of the flame on the metal being reheated.

When applied to recuperative furnaces, the size of the recuperators needs consideration. Incomplete combustion or a high ash content in the oil employed may cause stoppage.

In larger furnaces of the open hearth type, the atomiser is usually connected with the burner tip by an oil pipe, as shown in Figure 3. This illustration shows a Blaw-Knox burner, which is one of the most popular types of burner used in America on open hearth furnaces. It will be noted that the atomiser is remote from the burner tip, which pivots on a metal ridge in the nose of the "dark-house." The nose of the dark house is normally a water-cooled casting. The atomiser and burner tip are connected by a ¼-in. diameter oil pipe. The burner tip is also water-cooled. The atomiser, which is at the rear of the dark house, is varied in size according to the capacity of the furnace to which it is applied.

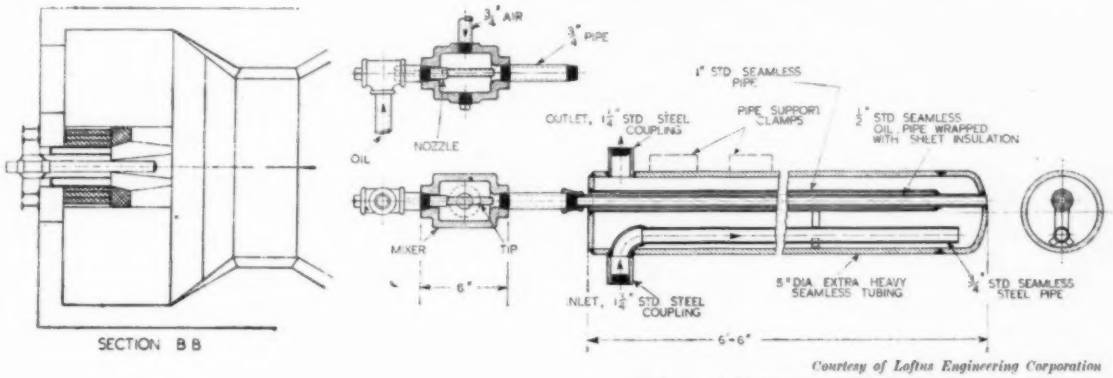
This type of burner is designed to consume from 3 to 10 gals. of oil per minute. On open hearth furnaces of 80 to 100 tons capacity, a burner supplying 4½ gals. of oil per minute may be taken as an average. With larger furnaces of 200 to 250 ton capacity, an average of 6½ gals. per minute may be required. On very large furnaces, the oil consumption during charging may be as high as 9 gals. per minute, and the oil input is gradually reduced as the heat progresses, so that at the end of the heat the consumption may be as low as 5 gals. per minute.

The burner illustrated in Figures 4 and 5, is the Loftus burner, and represents another type of burner employed in America. This burner is a more rigid design and it will be noted that it pivots from a support at the rear of the dark house. There is always a tendency for slag to accumulate around the nose of the dark house, and if the tip of the burner is free, as it is

in this design, it is an obvious advantage where such trouble is likely to occur.

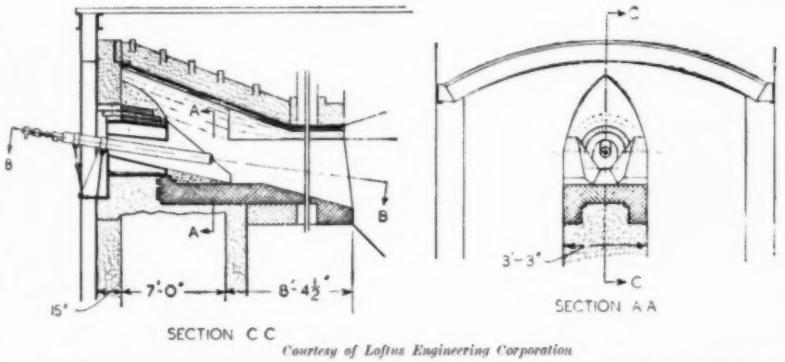
The chief structural alterations necessary to open hearth furnaces employing liquid fuel, concern the port design, the uptakes and the regenerators.

The gas port of the conventional gas-fired furnace is replaced by a refractory structure, referred to as the dark house. This dark house, through which the burner enters the furnace, acts as a sheath or protection for the burner. When dimensioning this dark house, ample space should be provided to allow the angle of the burner to be adjusted, so as to obtain correct flame direction. Lateral adjustment of the burner is also desirable.



Courtesy of Loftus Engineering Corporation

Fig. 4.—Oil-burner assembly.



Courtesy of Loftus Engineering Corporation

Fig. 5.—Arrangement of the Loftus burner.

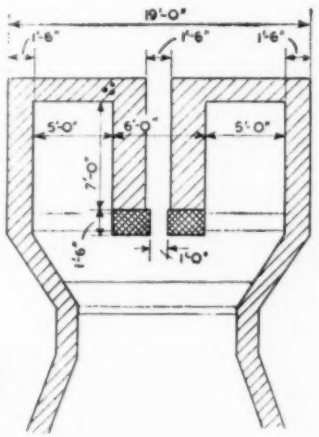


Fig. 7.—Plan of block of typical oil-fired open hearth furnace.

Since the air ports and uptakes have to accommodate all the waste products of combustion, which are approximately the same volume as in a gas-fired furnace of the same capacity, they must be much larger than the air uptakes of a conventional gas-fired furnace. Any restriction in the uptakes either slows down the rate of combustion or involves high velocities in the waste products, which results in greater erosion of the brickwork. Fig. 7 shows a typical block.

Only air regenerators are necessary. On smaller furnaces up to about 100 ton capacity, one large regenerator is provided at each end of the furnace. Damper type reversing valves are normally employed for controlling the flow of the air and the waste products of combustion.

On larger furnaces it is common practice to provide two air regenerators at either end of the furnace. The span of the regenerator arch on these large furnaces tends to become excessive, and is thereby weakened. This disadvantage is overcome by the use of dual air regenerators.

The air required for combustion is usually enforced by a fan of adequate capacity. The volume of air is normally controlled by means of a damper or vanes at the air inlet on the suction side of the fan. This method allows the fan to be operated at a constant speed and the air volume regulated by adjustment of the damper or vanes.

When dual regenerators are employed, the common air duct leading from the impelling fan divides, one branch leading to the reversing valve connected with each regenerator. Since a separate reversing valve is used on each circuit, the weight of this mechanism is reduced with obvious advantages. It is also desirable that each leg of the air duct is provided with a damper or similar device for controlling the flow of air through either regenerator. It is often an advantage to be able to vary the flow of air through a regenerator, when temperature differences exist in the two chambers.

Dampers should also be provided in the flues leading from the regenerators to the reversing valves. These dampers enable the flow of the hot-waste products of combustion to be regulated, thereby assisting the control and equalisation of regenerator temperatures.

The reversal of the oil flow and the atomising steam can be achieved in several ways. Normally, as the branch pipe leading to the individual installation

leaves the ringmain, a regulating valve, by means of which the oil flow can be controlled, is inserted. Beyond the regulating valve a line heater, generally a steam heater, is provided, and this is thermostatically controlled by a thermostat situated just before the pipe line reaches the reversal control.

At some plants the oil and steam is reversed by ordinary cut-off valves on the pipes leading to either burner. When this method is in operation, reversal should be performed in a definite sequence. When reversing, the oil should be turned off one burner, followed by the atomising steam. The steam is then admitted to the other burner, followed by the oil. This practice prevents deposits forming in the burner tips.

A better method is probably the employment of L ported plug valves, in which one leg is connected with the oil supply and the other two legs with either burner. This method is illustrated in Figure 2.

A similar arrangement is adopted for reversal of the atomising steam, except that a small volume of steam—known as "dead end" steam—is by-passed the reversing mechanism. This "dead steam" is generally necessary when a burner is on the exhaust end of the furnace, to avoid deposition in the burner. This "dead end" steam may amount to from 200 to 250 lbs. per hour.

Instruments and Furnace Control

A high degree of instrumentation is recommended if the best results are to be attained. The air/oil ratio must be carefully controlled if the maximum thermal efficiency is to be maintained. Oil and air flow meters should be installed. Some plants have adopted automatic control of this ratio, so that any variation in the oil flow, immediately adjusts the air input to maintain the correct ratio. The efficiency of combustion can be checked by CO_2 meters in the waste gas flues.

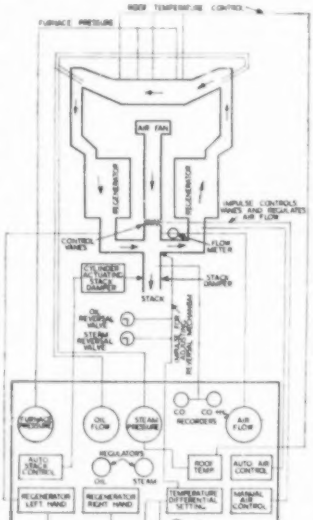


Fig. 8.—Suggested control panel for an oil-fired furnace.

Infiltration of air can be reduced to a minimum by the employment of a furnace pressure indicator. The maintenance of a slight positive pressure within the furnace prevents the filtration of air. This pressure is generally determined near the roof. In some cases, the impulse of the instrument is caused to activate the stack damper or the speed of the waste heat boiler fan. At other plants a clear indicator of the furnace pressure permits manual control of the stack damper or waste heat boiler fan.

Pyrometers recording regenerator temperatures are highly desirable. These permit an accurate heat balance to be maintained. It is also possible to reverse the furnace on a definite temperature differential. In some cases, a warning light or siren for indicating the attainment of the set temperature differential allows manual control of reversal. At some plants automatic reversal on a set temperature differential is adopted.

The older method of recording regenerator temperatures by optical pyrometers sighted on the regenerator brickwork has been largely superseded. Modern practice favours the use of base metal thermocouples either at the base of the regenerators or in the flues leading from the regenerators to the reversing valves.

The introduction of roof temperature control has resulted in considerable increase in output and economy of refractories at many plants in America and in this country. The roof temperature may be recorded by thermocouples bricked into the roof, or by means of optical pyrometers sighted from the back wall on to the roof of the furnace. The latter method appears to give the better and more consistent results. Usually, three pyrometers are used. One is sighted on the centre of the roof and the other two are placed equidistant between the centre and the furnace ports.

Normally, a safe maximum temperature is set and the fuel input controlled so as to attain this temperature. This practice assures a maximum safe temperature being maintained, resulting in maximum rate of output and economy in refractories.

Here again the fuel input may be regulated manually by the aid of warning lights or sirens, or it may be automatically controlled. In automatic control, an impulse from any of the pyrometers may activate the oil flow valves.

The subject of instrumentation of open hearth furnaces was very ably reviewed by Smithson[3] and Bradley,[4] whilst Figure 8 shows an attempt to represent graphically the control requisite on an oil-fired open hearth furnace and the type of panel which would give satisfactory results.

Use of Tar and Tar Oils

This article has dealt chiefly with the employment of fuel oil, but the same general principles apply to the use of tar and coal-tar oils. When using tar and tar oils, some modification to burner design and the temperature of circulation and atomisation may be required.

Coal-tar fuels, however, should never be mixed with petroleum fuels, otherwise changes in physical properties occur and render the mixture unfit for use as a liquid fuel.[5] When a change from one type of fuel to another is necessary, the whole system should be thoroughly cleansed before admitting the new fuel. Some authorities recommend the use of creosote for cleansing purposes.

It should also be remembered that coal-tar fuels are heavier than water, and therefore any water they contain will float to the surface of the storage tanks. With petroleum fuel oils the reverse is true.

Although the present change from solid to liquid fuels, is largely due to the shortage of coal, it is possible that with increased thermal efficiency and other economies which may be effected, the use of liquid fuel may become the practice of the future. The successful application of oil to open hearth furnaces in America, where the price differential between coal and fuel oil is much the same, is some criterion. Since our fuel oil has to be imported, however, the final decision may be a question of national policy rather than one of thermal and economic efficiency.

3 Smithson. *Metallurgia*, February, 1938.
4 Bradley. *Iron and Steel Engineer*, September, 1934.
5 Coal-tar Fuels. *Assoc. of Tar Distillers*, 1944.

Creep and some Creep-resisting Alloys

By G. Burns, M.Met.

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Spectacular improvements have been made in the past few years in materials to withstand high temperatures and high stresses. The development of gas turbines, in particular, depends on the continued improvement in these materials and their capacity to resist creep, a phenomenon which places a limitation on the life at elevated temperatures of structures where only limited changes of dimensions can be tolerated. In this article attention is directed to this phenomenon, to design information, use of data, future requirements, and to some ferrous and non-ferrous creep-resisting alloys.*

IN the ordinary course of events components are designed to work at stresses within a fairly well defined elastic limit: when under stress they immediately take up a strain proportional to the stress and, on release of the stress, return to their original dimensions. Above some temperature level, which is dependent on the material, a new mode of behaviour under stress becomes observable; as the stress is applied the material behaves at first in a manner generally similar to behaviour in the elastic range at normal temperatures but with a Young's Modulus lower than that found at atmospheric temperature, but when the full desired load is reached the strain does not quickly attain some maximum stationary value, it continues to increase at a greater or less rate over periods which may be very long and which probably always end in failure of the component. This continuing strain with constant load is the phenomenon generally known as creep which, obviously, places a limitation on the life at elevated temperatures of structures in which only limited changes of dimensions can be tolerated.

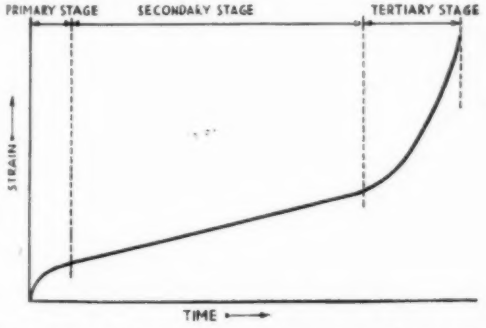


Fig. 1.—General form of strain/time curve after attaining full load (elastic extension ignored).

The general behaviour of material in which creep is occurring is shown in the strain/time curve in Fig. 1, and it will be observed that the curve is separable into three stages, generally referred to as the primary, secondary and tertiary stages of creep. During the primary stage, which is of fairly short duration, strain is rather rapid, but the rate of straining is diminishing; in the secondary stage, which may be very long, the strain rate is approximately constant and relatively small. After the secondary stage has lasted for some time the creep rate accelerates increasingly and failure by rupture occurs in a fairly short time. It is not yet certain what mechanism is in operation during the various stages of creep.

* From "Papers on Engineering Subjects," by courtesy of Department of Chief of Naval Information. (Slightly abridged.)

Necessary Design Information

One of the designer's first concerns is that at the stress and temperature to which a component is subjected the material shall not enter upon the tertiary stage of creep within the anticipated working life of the component since, once this stage is reached, failure is imminent. There is, at present, no method of estimating, from the form of the curve in the primary and secondary stages, when the tertiary stage of creep will commence: this factor has to be determined by direct experiment. However, when some amount of consistent data has been obtained for a given material and temperature it is possible to draw a curve relating stress to time for commencement of tertiary creep and to obtain from this curve the times at which the tertiary stage may be expected to set in under other stresses than those used experimentally; it is probable that the curve may be extrapolated to a small extent, but this should not be carried far outside the experimental conditions.

The next point of interest to the designer is the amount of strain which may be expected in a given time under the designed conditions of stress and temperature, or, conversely, what conditions of stress and temperature may be imposed without exceeding some selected strain in a certain time. To obtain this information the first step is to obtain curves of the type shown in Fig. 1 for various stresses at each temperature. If the information required is the amount of strain to be expected in a given time for certain values of stress and temperature, it can be derived direct from the curve. If it is required to know the stress which will give a specified amount of strain in a certain time, then the method is to read off from each curve for the appropriate temperature the time for the specified amount of creep to occur and to plot a time/stress curve; by interpolation, or by extrapolation provided that it is not carried too far, the stress which will give the specified strain in the required time can be read off.

Presentation of Data

The strain/time curve, as usually presented, does not take any account of elastic strains, it being assumed that the designer will normally make allowance for elastic strains and only requires a knowledge of the permanent strains for which additional allowance must be made. Methods of reporting in figures the data obtained from a strain/time curve differ, some workers reporting total

creep strain against time, while others, and that the majority, more often report creep rate in the secondary stage. This latter method of reporting is unfortunate since it takes no account of the strain in the primary stage which may be a significant portion of the permissible strain. As an instance taken from actual test results may be quoted a material which under certain conditions of stress and temperature gave a steady creep rate in the secondary stage of 10^{-7} in./in./hr. equivalent to 0·1% strain in 10,000 hours; on this basis the material might appear acceptable for an application involving 0·1% strain in this time, but on examining the full curve it appears that in the primary stage 0·03% strain occurred, one-third of the total strain considered permissible so that the total strain would actually be reached in about two-thirds of the required life. Even more striking instances than this could be cited and for this reason it is considered that the method of reporting total strain against time is much to be preferred.

Another convenient method of presenting the data, when sufficient results have been collected, is in the form of curves giving stress and temperature conditions appropriate to certain rates of creep strain, say, 0·1% in 1,000 hours or 1% in 10,000 hours. When making use of data presented in this form it is very necessary to know the duration of the tests on which the results are based; so far as creep rate is concerned 0·1% in 1,000 hours is the same as 1% in 10,000 hours, but it would not be sound practice to take stresses appropriate to 0·1% in 1,000 hours, based on tests of 1,000 hours duration, and apply them to a case where 10,000 hours life is required and 1% strain is admissible; the stress which gives 0·1% strain in 1,000 hours might cause failure in a shorter period than 10,000 hours.

Future Requirements

Turning now to future requirements in materials for advanced steam conditions and for gas turbines, there is extremely little date available directly applicable to an estimate of materials suitable for these applications, and not very much more data can be reasonably extrapolated to these conditions.

The measurement of small strains occurring in very long times is, evidently, work requiring equipment of great sensitivity and precision quite apart from the time-consuming aspect of long duration tests. The amount of equipment in existence of adequate sensitivity to measure strains of the order involved is small and, in view of the wide field of materials and temperature conditions to be explored when all high temperature applications are considered, it is not surprising that most of the testing carried out has been of relatively short duration, mostly of the order of 300 to 1,000 hours, and rarely exceeding 2,000 hours. Further, the amount of strain regarded as acceptable has generally been of the order of 1%, so that more often than not stressing has been such that more than 0·1% strain has taken place in the primary stage. Any attempt to extrapolate results of tests which had in mind 1% strain in 1,000 hours to conditions which may be considered many times different, must be regarded as completely unsafe. Some very long duration tests have been carried out at lower temperatures but are not applicable to the present problem.

In considering what materials may have good resistance to creep under severe conditions, it may be mentioned that it is a matter of observation that there is some parallelism between the melting points of metals and their creep resistance. The metals of highest melting points which are available in sufficient quantity to be used for structural purposes are iron, nickel, cobalt and chromium, and the majority of creep-resistant materials in current use are based on iron, nickel and chromium, though there is a growing tendency to introduce cobalt to a greater extent than hitherto. All of these metals may be strengthened by alloying with other elements which go into solution in the basis metal, and also by addition of elements which form compounds and give either dispersed second phases or precipitation hardening effects.

Low Alloy Steels

Up to about 550° C. low alloy steels of the ferritic type exhibit a fair degree of resistance to stress and are generally used; the alloy elements most favoured for increasing the creep resistance of the basis plain carbon steel being chromium and molybdenum, sometimes with the addition of vanadium. Above 600° C. it is necessary to go to highly alloyed steels of the austenitic type or to non-ferrous alloys, usually based on nickel and chromium, and generally it has been found desirable to add small percentages of other elements which confer precipitation hardening effects on the basis alloy.

Although it is known in a general way what alloy elements are most effective in promoting resistance to creep, and there is increasing knowledge of an empirical kind as to the relationship between microstructure of a given alloy and its creep resistance, it cannot be said at present that all the factors affecting creep resistance are fully understood or fully under control and there is not, as yet, any certainty that one batch of a given material will behave in a precisely similar manner to another batch nominally identical with it; such discrepancies as exist from batch to batch, while they may not be of great importance in fairly short life components may produce marked differences in the final result over a long life. It is, therefore, necessary to allow some margin of safety when considering results obtained from one batch of material, since other batches may behave slightly differently.

Materials in Regular Production

Materials which may be of use for high-duty steam turbines or for gas turbines and which are in regular production, as distinct from experimental alloys not yet produced in volume on a commercial scale, are:—

1. *Ferritic Steels*
   - (*a*) 1% chromium, 0·5% molybdenum.
   - (*b*) 3% chromium, 0·5% molybdenum.
   - (*c*) 3% chromium, 1·0% molybdenum.

   NOTE.—Any of the above steels may be further improved by a small addition of vanadium, but this is not very general practice as yet.
2. *Austenitic Steels*
   - (*a*) 20% chromium, 8% nickel with additions (Stayblade, etc.).
   - (*b*) 15% chromium, 15% nickel with additions (Rex 78, Jessops G18B, etc.).
   - (*c*) 11% chromium, 35% nickel (A.T.V., etc.).
2. *Non-ferrous Alloys*
   - (*a*) 80% nickel, 20% chromium with additions (Nimonics).

It must be appreciated that the compositions given above, particularly for the austenitic steels, are very approximate, and that the amount of alloy elements

present in individual alloys of a type may vary appreciably from the figures given above as indicative of the type. Material of the type mentioned under (2) (*a*) above is represented by Stayblade, for which there is data relating to rather high-creep rates at low durations, data which cannot be extrapolated to meet the conditions set out above. Material of type (2) (*b*) is represented by Rex 78 (Brown-Firth) and also by G.18B (Jessop). So far as can be inferred from extrapolation of the known data on Rex 78 it might be expected to give 0·1% strain in 1,000 hours at 650° C. under a stress of 10 tons/sq. in. G.18B tested at 650° C. gives a creep rate in the secondary stage of 10^{-6} (0·1% strain in 1,000 hours) under a stress of about 12 tons/sq. in.: the stress for 0·1% total strain in 1,000 hours would be somewhat lower than this. Material of type (2) (*c*) is represented by A.T.V., which has been in use for many years for turbine blading, but for which no creep data applicable to the conditions under consideration is known. The non-ferrous nickel-chromium alloys are represented by Nimonic.

Criteria Considered Acceptable

One general point which may require consideration is the grounds on which requirements are to be based; at present it appears possible that the maximum temperature and maximum stress which may be anticipated, and the maximum strain which is considered acceptable are the criteria. In components such as turbine rotors and blades the maximum conditions of stress and temperature do not occur at the same position, and it is very likely that the most severe combination of temperature and stress occurring in the component is appreciably less exacting than would be suggested by considering the maximum conditions of both factors. Further, the most arduous conditions probably only operate in a restricted region, conditions on either side of this region being less severe, and the strain occurring in these regions being less than the strain in the portion subjected to the most severe conditions; this would indicate that a strain rate might be accepted for the region of most severe conditions appreciably higher than is considered acceptable for the component as a whole.

The Determination of Tin and Copper in Phosphor-Bronze

By Brian B. Bach, B.Sc., A.R.I.C.

Methods are described for the determination of tin and copper in tin-bronze; they are proposed with a view to overcoming the difficulties introduced by the presence of phosphorus and have been designed to give accurate results in reasonable time. Modifications are suggested to cover other copper alloys.

THE analysis of phosphor-bronze presents difficulties due to copper and phosphorus contaminating the metastannic acid precipitate obtained by dissolving the alloy in nitric acid. On several occasions, the author has found up to 1% of copper and phosphorus trapped in this precipitate. Several methods have been advocated to overcome these difficulties, such as volatilisation of tin with ammonium iodide,[1] fusion of impure stannic oxide, and determination of impurities,[2] etc. However, as none of these methods was found by the author to be really satisfactory an investigation into the possibility of determining tin and copper electrolytically was instigated.

Both copper and tin can be determined by deposition under conditions of controlled potential,[3] but for routine work it was decided that this was not convenient.

Accordingly, pure tin solutions were prepared and various electrolytic procedures tested. Those tried included deposition from chloride,[4] ammonium oxalate[5] and sulphuric/oxalic acid[6] solutions. As the latter gave very promising results, it was decided to base the preliminary experiments on this method.

It was necessary to obtain the tin in solution as sulphate, free from oxidising agents such as nitric acid. Initially, this was done by dissolving in sulphuric/nitric acid mixture with complete removal of nitric acid by prolonged fuming. Later, however, a method for dissolving copper alloys in sulphuric acid (by addition of hydrogen peroxide) was published by Edwards and Gailer[7] and has since been incorporated.

The next problem was how best to remove copper. Removal by displacement with more electropositive metals was tried, but gave low results in every case owing to co-precipitation of tin with copper.[8,9] Finally, it was decided to remove the copper electrolytically after forming a complex stannifluoride by addition of fluorine ions. This was originally done by means of hydrofluoric acid, but later it was found more convenient to use sodium fluoride.

In order to deposit the tin it was necessary to decompose the complex and this was accomplished by means of boric acid[10] which presumably forms a more stable borofluoride.

The final procedure adopted was as follows:

To 1 gm. of fine drillings add 20 ml. cold 50% sulphuric acid and then carefully add 15 ml. 30% hydrogen peroxide (100 vol), avoiding loss due to vigorous effervescence.

Boil to decompose all hydrogen peroxide and dilute to *ca.* 100 ml.

Add 1·0 gm. sodium fluoride or 2–3 ml. 40% hydrofluoric acid and leave to stand for 1 hour.

1 *Text Book of Quantitative Analysis*, Vogel, p. 520 and p.632.
2 *Analytical Chemistry*, v. II, 9th Edition. Treadwell and Hall, p. 101 and 94, 8th Edition, p. 224 and p. 231.
3 *Electrochemistry and Electrochemical Analysis*, v. II. Sand, p. 62.
4 *Loc. cit.* Sand, p. 72.
5 *Loc. cit.* Sand, p. 72.
6 *Loc. cit.* Sand, p. 72.
7 *Analyst*, 69·819, p. 169.
8 *Analyst*, 1931, 56, 82.
9 *Analyst*, 1944, 69·823, p. 291.
10 *Loc. cit.* Sand, p. 93.

Filter through Whatman No. 44 filter-paper to remove lead as sulphate and wash with cold dilute sulphuric acid (5%).

Electrolyse for 1 hour at 2–3 amps. using gauze electrodes (for dimensions of electrodes see General Note 1).

Remove electrodes and wash well with cold water.

Add 5 gm. oxalic acid, 5–10 gm. boric acid and 5 ml. ammonium hydroxide (s.g. 0·880).

Heat to 70° C., add 1–2 gm. hydroxylamine or hydrazine sulphate, and electrolyse for 1 hour at 4–5 amps., using a rotating, tared copper-coated, gauze cathode. (See General Note 1).

Wash rapidly with cold water, dip into alcohol and dry at 100° C.

Increase in weight = Weight of tin.

Notes

1. Excess hydrofluoric acid should be avoided.

2. The determination should be completed as soon as possible after addition of hydrofluoric acid or sodium fluoride to avoid separation of hydrated silica, which collects on the cathode.

3. Tin is best removed from the cathode by means of a hot mixture of hydrochloric and oxalic acids and subsequent removal of copper with nitric acid after rinsing well to remove hydrochloric acid.

Copper

For the determination of copper it was decided to make use of the same reaction between fluoride and stannic ions (formation of stannifluoride) already used.

From a plain sulphuric acid solution—i.e., free from nitric acid under the conditions used for the preceding method, the copper deposit, for quantitative work, was unsatisfactory. This was due to the liberation of hydrogen at the cathode during the later stages of electrolysis. It was, therefore, decided to use a separate sample for the copper determination.

Experiments were first made to ascertain whether phosphor-bronze would dissolve in a mixture of nitric and hydrofluoric acids as used by Sand,[11] for separation of tin and lead. No difficulty was experienced in obtaining complete and rapid dissolution.

The resulting solution was electrolysed after dilution with water and addition of sulphuric acid. Very good results were obtained in the absence of lead, but above about 0·2% the results were erratic. However, as many phosphor-bronze samples are free from lead, this method was adopted provisionally.

A modification was evolved later in which lead was removed as sulphate prior to electrolysis. It was identical with the method for tin until the lead sulphate was filtered. Nitric acid was then added and the solution electrolysed. A good copper deposit was thus ensured and interference by lead was eliminated, rendering the method more widely applicable, though the time required was somewhat increased.

The two methods finally evolved for copper were as follows:—

(*a*) *Lead up to* 0·2%.—Dissolve 1 gm. drillings in 5 ml. nitric acid (s.g. 1·42), 10 ml. water and 1 gm. sodium fluoride, or 2–3 ml. 40% hydrofluoric acid. Boil gently to remove fumes and cool. Dilute to 150 ml. with cold water, add 5 ml. sulphuric acid (s.g. 1·84) and electrolyse with rotating tared cathode at 3 amps. for 1 hour. Add 1 gm. urea to eliminate nitrous acid and leave for 2–3 minutes longer. Remove electrodes, wash rapidly with cold water, dip into alcohol and dry at 100° C.

Increase in weight = Weight of copper present.

(*b*) *Lead over* 0·2%.—Proceed as for determination of tin until the lead sulphate has been filtered, add 5 ml. ammonium hydroxide, (s.g. 0·880), to adjust acid concentration and then 5 ml. nitric acid, (s.g. 1·42.) Electrolyse with rotating, tared cathode at 3 amps. for 1 hour as in previous method and continue as before (add urea, etc.).

General Notes

1. In all cases the electrodes were made of platinum gauze approximately 20 mesh. The cathode was a cylinder about 1 in. dia. and 1½ in. long, it being rotated at approximately 500 r.p.m. The anode was also cylindrical, about 1¾ in. dia. and 1½ in. long.

2. In either determination the lead sulphate precipitate can be used for the determination of lead. However, as hydrated silica may be precipitated at the same time, it is advisable to purify with ammonium acetate and subsequently precipitate by any standard method—i.e., as chromate, molybdate, etc.

3. The above methods can be applied equally well to other alloys—e.g., brass, gunmetal, etc., but satisfactory results have not been obtained for tin in high nickel alloys.

Time Required

For duplicate tin determinations, approximately 5 hours.

For duplicate copper determinations by method (*a*) approximately 2 hours.

For duplicate copper determinations by method (*b*) approximately 3 hours.

It must be realised, however, that these figures are total times, not operational times.

Accuracy

Tin up to 5%	±0·04%
Tin from 5%–15%	±0·06%
Copper from 60%–100% ..	±0·05%

Conclusion

Methods have been proposed in order to overcome the difficulties introduced by the presence of phosphorus in tin-bronze and have been modified to cover other copper alloys. They have been designed to give accurate results without undue loss of time.

As a result of research work carried out over a period of many years, it is well established that nickel can be alloyed in all proportions with cast iron, giving a series of materials of great interest to engineers. Much information concerning this series of cast irons is given in a recent reprint of a publication on the subject in a revised form. It will be of special use to engineers and designers in assisting them in their choice of materials for particular purposes. The booklet contains information and data concerning low-nickel cast iron, high-duty nickel cast iron, nickel-molybdenum and acicular cast iron, hard and heat-treatable grey iron castings, nickel in white iron castings, corrosion—and heat-resisting austenitic cast iron, and certain special alloy cast irons. Copies may be obtained, free of charge, from The Mond Nickel Co., Ltd., Grosvenor House, Park Lane, London, W. 1.

11 *Loc. cit.* Sand, p. 94.

Contact Corrosion Problems in the Metal Window Industry

An Assessment of their Relative Importance

By E. F. Pellowe, B.Sc., A.R.I.C. and F. F. Pollak, D.Sc., A.R.I.C.

The contact corrosion of cast aluminium to steel, galvanised steel, brass, pure aluminium and stainless steel has been studied. The method adopted was to make accurately weighed discs of the various materials; these were placed in contact and the pairs of discs were submitted to a period of immersion in salt solution and water followed by a period of drying. This treatment continued for several weeks and the samples were then cleaned and re-weighed; control sets of similar metals were included to assess the increase of attack due to dissimilarity; the systems were studied in the painted and unpainted condition. The results: (1) For metal to metal contact are of the same order as those obtained by the American Society for Testing Materials. (2) Form an addition to our knowledge in that they deal with commercial alloys rather than with pure metals. (3) Indicate that as far as these painted systems are concerned, contact corrosion is negligible. (4) Fill a gap in the A.S.T.M. figures since the latter omit the aluminium/iron system.

Introduction

A METAL window consists essentially of an outer and inner frame; the inner frame swings on hinges, and when closed the contact of the two sections is as indicated in Fig. 1. The finished products are normally painted or hot-dip galvanised and the fittings—i.e., stay or handle on the steel window may be brass or bronze. With the introduction of the cast aluminium frame the authors became interested in the possibility of accentuated corrosion with particular reference to the couples set up when:—

(*a*) Cast aluminium alloy and steel.
(*b*) Cast aluminium alloy and galvanised steel.
(*c*) Cast aluminium alloy and brass.
(*d*) Cast aluminium alloy and pure aluminium.
(*e*) Cast aluminium alloy and stainless steel

are in contact.

When two different metals are in electrical contact, a current flows between them leaving a residual EMF (or Potential Difference) equal to current × resistance of the cells. This potential difference is often expressed in millivolts, and Table I lists the millivolt potentials of various metals (measured in 3% sodium chloride solution at 18°–20° C.).

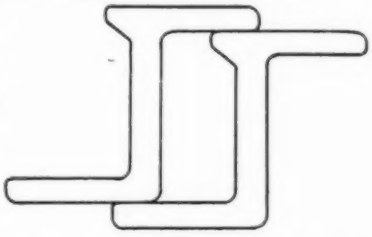


Fig. 1.—Showing contact of outer and inner frames.

TABLE I
ELECTROLYTIC POTENTIALS OF VARIOUS METALS AGAINST PURE ALUMINIUM (1)

Metal	Potential (mv)	Metal	Potential (mv)
Magnesium	−850	Tin	+300
Zinc	−350	Brass (50% Zinc)	+500
Cadmium	−20 to 0	Nickel	+500
Pure Aluminium	0	Brass (30% Zinc)	+500
Alloys (A.W. 3, 6, 7)	+100	Copper	+550
Alloys (A.W. 15)	+150	Silver	+700
		Mercury	+750
Iron and Mild Steel	+50 to +150	Stainless Steel	+400 to +700
Lead	+250	Gold	+950

1 Table III. A.R.C. Techn. Rep., H.M.S.O., 1942.

As is well known when two dissimilar metals are in contact their corrosion rates will generally speaking be no longer the same as when they are not in contact. The corrosion rate of the more electro-positive will be increased and that of the more electro-negative will be retarded.

This fact has been commercialised in the hot-dip galvanising, sherardising and zinc spray processes, where steel is given a coating of zinc. The zinc corrodes sacrificially thereby protecting the steel. Similarly, aluminium coatings are sometimes used for steel wire; pure aluminium is used to coat copper-bearing aluminium alloys and cadmium plating is used for steel. Tin plating, chromium plating and nickel plating of steel, however, protect the base metal only mechanically and when the coating is broken the remaining coat accelerates the corrosion of the steel.

Table I can be used to find out which metal is likely to protect another and which metal would corrode faster. At best it can only indicate a tendency, however, for the corrosion rate depends upon the current flowing and not upon the EMF alone and thus the cell resistance is involved. Owing to polarisation, corrosion may drop off; Fig. 2 illustrates this with a simple brass/aluminium cell in 3% sodium chloride solution. Furthermore, the areas in contact may be uneven and unequal and this affects the corrosion rate too.

Everyday Examples

In spite of different potentials, copper and steel occur in contact in locomotive boilers without serious trouble.[2] Iron with lead and copper with brass give no trouble in plumbing.[3] Steel rivets have given no trouble in an aluminium bridge even after 10 years exposure.[4] Aluminium in contact with stainless steel has given no serious corrosion[5]. Kenworthy[6] has, however, described the extensive damage when copper pipes exist in contact with galvanised iron cisterns, but the explanation indicates that the water dissolves copper and re-deposits

2 T. H. Turner. *J. Iron Steel Inst.*, 1934, 129, 361.
3 H. Cassell. *Korr. Met.*, 1925, 1, 75.
4 Private communication.
5 M. R. Whitmore and J. Teres. *Ind. Eng. Chem.*, 1939, 31, 608.
6 L. Kenworthy. *J. Inst. H.V. Eng.*, 1940, 8, 30; *J. Inst. Met.*, 1943, 69, 67.

it on the zinc. The copper bottoms of ships are considered to accelerate the corrosion of steel ships in the same docks.[7]

Cases of serious failure due to copper/aluminium contacts are reported[8] and brass rivets have given

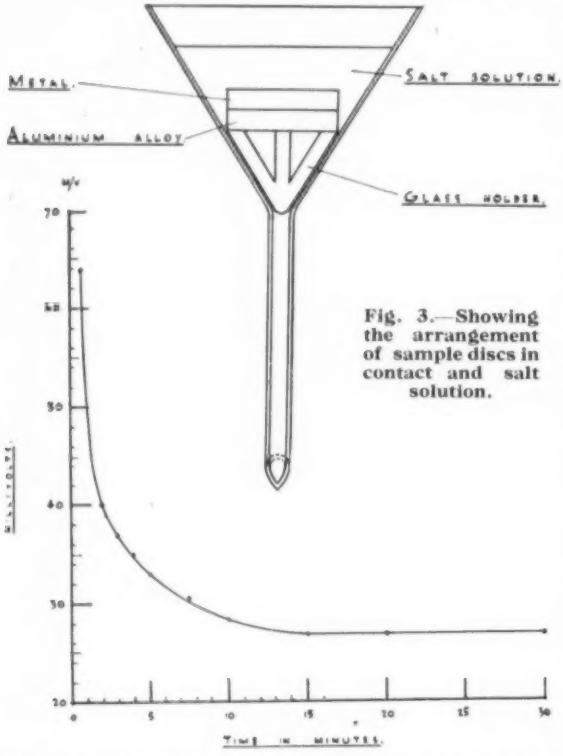


Fig. 2.—Corrosion drop due to polarisation indicated with a simple brass/aluminium (LAC 112A) cell in 3% sodium chloride solution.

Fig. 3.—Showing the arrangement of sample discs in contact and salt solution.

TABLE III

Couple	Weight loss in mg. after three years exposure		Value corrected for normal Corrosion. Increase or decrease of loss as compared with the loss of the single metal couple
			mg.
Aluminium to Aluminium	39 to 66	mean 53	
Aluminium to Copper	462 to 41		+409 −102
Aluminium to Iron	? to 1258		
Aluminium to Zinc	10 to 697		−1684 − 43 +273
Copper to Copper	136 to 150	mean 143	
Zinc to Zinc	370 to 478	mean 424	
Iron to Iron	2684 to 3199	mean 2942	

trouble with duralumin in aircraft.[9,10] A coat of protective paint is said to prevent corrosion in these cases.

7 H. E. Skinner. *Tr us. Inst. Nav. Arch.*, 1939, 81, 323.
8 H. Hänlich. *Aluminium*, 1941, 23, 389.
9 P. Mabb. *Metallurgia*, 1936, 14, 29.
10 Hamard, *J. Lutte Cor.*, 1938, p. 396.

The published literature dealing with this type of corrosion is limited to a few specialised examples: it does not as a rule deal with the corrosion of alloys but with pure metals and it does not cover painted systems.

Perhaps the most comprehensive system of experiments is that carried out by the American Society for Testing Materials.[11]

Thin discs of different metals were weighed and placed in close contact, out into the weather at various stations all over America. From time to time the discs were then re-weighed. Control pairs of discs of similar metals to assess the normal corrosion of the various metals were also incorporated.

Table III is extracted from the figures given by A.S.T.M. for the Californian station.

These figures deal with pure metals only; those for aluminium to iron were destroyed by accident and are not available.

Arrangement of Authors' Experiment

Discs from various metals were prepared as described under the heading, "Materials Used." They were degreased with trichlorethylene and dried. In the case of painted specimens two coats of paint were applied by dipping, each coat being stoved at 350° F. for 30 mins. The LAC 112A discs were subjected to a chromate treatment prior to painting. All weights were recorded.

Twelve glass funnels of 100 ml. capacity were fitted with inverted glass tripods to support the specimens and with rubber tubing and spring clip for the draining of the corrosive liquids. The discs were placed so that a contact was given over the whole flat surface and LAC 112A was in every case the bottom specimen. The whole arrangement is shown in Fig. 3.

The funnels were filled daily with fresh 3% solution of sodium chloride (Analar) in distilled water and a cycle arranged so that the specimens were immersed for eight hours a day for a total period of 30 days. After that a similar treatment with tap water (pH = 8·0) followed for another 30 days. Finally, the specimens were inspected and then freed from corrosion products with aid of the following reagents:—

LAC 112A and Super-purity Aluminium with cold conc. nitric acid. Mild Steel and Stainless Steel: Inhibited Cold 1 : 1 hydrochloric acid. Brass: Cold 1 : 4 hydrochloric acid. Zinc: Inhibited cold 1 : 4 sulphuric acid.

The painted specimens were cleaned by dipping in cold 1 : 4 sulphuric acid. Only the mild steel specimen had to be stripped of paint as this was blistered at the edge and the corrosion products were removed with inhibited 1 : 1 hydrochloric acid.

All specimens were washed thoroughly after the acid treatment, dried and weighed.

Materials Used

(*a*) Aluminium Alloy LAC 112A (gravity diecast).

Analysis	Silicon	10·43%
	Copper	1·73%
	Nickel	0·43%
	Iron	0·62%
	Manganese	0·64%
	Magnesium	0·10%
	Zinc	0·21%
	Titanium	0·10%

(*b*) Mild Steel (drawn).

Analysis:	Carbon	0·14%
	Silicon	0·01%
	Manganese	0·78%

11 A.S.T.M., Plate III, Vol. 35, Part I.

	Nickel	Trace
	Sulphur	0·062%
	Phosphorus	0·078%
(*c*) Brass (diecast).		
Analysis :	Copper	58·43%
	Tin	Trace
	Lead	2·25%
	Iron	0·12%
	Nickel	Trace
(*d*) Super-purity Aluminium (rolled).		
Analysis :	Silicon	0·009%
	Iron	0·003%
	Copper	0·001%
(*e*) Zinc (cast).		
Analysis :	Tin	Trace
	Lead	1·06%
	Iron	0·004%
	Cadmium	0·008%
(*f*) Stainless Steel (drawn).		
Analysis :	Carbon	0·13%
	Silicon	0·67%
	Nickel	8·27%
	Chromium	18·41%
	Manganese	0·35%
	Sulphur	0·008%
	Phosphorus	0·011%

(*g*) Chromated Red Oxide High Temperature Stoving Primer.
Analysis: Pigment 33·3% (red oxide with 5% zinc chromate).

	Oils and Gums	23·3%
	Volatile	43·4%

p/v = 100/67.
Viscosity .. .. 24 (Ford cup 70° F.)

The vehicle is phenolic resin modified with linseed oil, the volatile a mixture of paraffin hydrocarbons and naphtha.

The metals a–f were machined into discs.

Diameter 1·578 ± 0·001 in. Thickness 0·197 ± 0·001 in.

From this: total area 4·887 sq. in. (mean) and contact area 1·955 sq. in. (mean).

Six systems were investigated :—

LAC 112A/LAC 112A. Mild Steel/LAC 112A. Brass/LAC 112A. Super-purity Aluminium/LAC 112A. Zinc/LAC 112A. Stainless Steel/LAC 112A.

Each system was studied in the painted and unpainted state.

The following tables show the result of inspection and estimation of loss in weight :—

TABLE IV
INSPECTION OF SPECIMEN AFTER THE CORROSION TEST. NOT PAINTED SERIES

System	Before Cleaning off Corrosion Products	After Cleaning off Corrosion Products
LAC 112A	All surfaces covered with an adherent white deposit.	Pitting over the whole of the surface.
LAC 112A	All surfaces covered with an adherent white deposit.	Pitting over the whole of the surface.
Mild Steel	Heavily rusted.	Heavily pitted.
LAC 112A	Contact area covered with rust, the rest with white deposit.	Pitting stronger on the contact area.
Brass	Upper surface slightly tarnished, contact area shows dezincification.	Copper film on contact area.
LAC 112A	Contact area shows more white deposit than the rest.	Pitting stronger on contact area.
Super - purity Aluminium	Only contact area shows deposit.	No pitting.
LAC 112A	Contact area shows more white deposit.	Pitting stronger on contact area.
Zinc	Upper surface covered with white corrosion products. Contact area is only slightly corroded.	No pitting.
LAC 112A	Contact area shows very little corrosion.	Contact area is not pitted.
Stainless Steel	No visible sign of corrosion except two small rust spots.	No visible sign of corrosion.
LAC 112A	Contact area shows more corrosion products.	Pitting stronger on contact area.

TABLE V
INSPECTION OF SPECIMEN AFTER THE CORROSION TEST. PAINTED SERIES

System	After Cleaning
LAC 112A	No visible corrosion, paint film unchanged.
LAC 112A	No visible corrosion, paint film unchanged.
Mild Steel	Paint blistered at the edge and on the top, causing slight pitting. Paint film unchanged on contact surface.
LAC 112A	No visible corrosion, paint film unchanged.
Brass	No visible corrosion, paint film unchanged.
LAC 112A	No visible corrosion, paint film unchanged.
Super - purity Aluminium	No visible corrosion, paint film unchanged.
LAC 112A	No visible corrosion, paint film unchanged.
Zinc	Slight blistering at the edge, no pitting.
LAC 112A	No visible corrosion, paint film unchanged.
Stainless Steel	No visible corrosion, paint film unchanged.
LAC 112A	No visible corrosion, paint film unchanged.

TABLE VI
THE LOSS IN WEIGHT DUE TO CORROSION

Unpainted Series System	Loss (mg)	Painted Series System	Loss (mg)
LAC 112A	64 ; mean	LAC 112A	+3 (gain)
LAC 112A	43 ; 54	LAC 112A	+3 (gain)
Mild Steel	2986	Mild Steel	341
LAC 112A	139	LAC 112A	+4 (gain)
Brass	63	Brass	2
LAC 112A	169	LAC 112A	+2 (gain)
Super-purity aluminium	10	Super-purity aluminium	Nil
LAC 112A	99	LAC 112A	+7 (gain)
Zinc	323	Zinc	16
LAC 112A	27	LAC 112A	+3 (gain)
Stainless Steel	3	Stainless Steel	Nil
LAC 112A	104	LAC 112A	+4 (gain)

TABLE VII (UNPAINTED SERIES)

Couple	Increase or decrease of loss as compared with the loss of the single metal couple	Loss as percentage of weight of disc
	mg.	
LAC 112A		0·32%
LAC 112A		
Mild steel	+ 44	6·0
LAC 112A	+ 85	0·82%
Brass	− 80	0·12%
LAC 112A	+ 115	1·0%
Zinc		0·7%
LAC 112A	− 27	0·16%
		0·086%
Stainless steel		
LAC 112A	+ 50	0·6%

Discussion of Results

(*a*) The losses in weight during the two months test are of the same order and in the same direction as those obtained during the three years natural corrosion with the A.S.T.M. test.

(*b*) The general tendencies in Table VI could have been foretold by Table I.

The corrosion of aluminium in contact with bare steel is somewhat greater than would be expected having regard to the low potential differences. Under the conditions of the experiment the iron corrosion products were extremely heavy, and it is suggested that the deposition of these upon the aluminium accentuated the attack.

Conversely, the potential difference of stainless steel and aluminium is large and the low corrosion increase is due presumably to passivation.

With the painted discs the paint film stood up to the conditions of test better than was expected ; the corrosion of all samples apart from the steel and zinc was practically nil and that due to contact did not arise ; the paint adhesion and water resistance was reasonable

throughout. On the steel and zinc discs the paint film broke down at the sharp edges of the machined discs and corrosion began at the circumference and worked inwards.

The bare aluminium/zinc couple is of particular interest. Here the aluminium was protected by contact with the zinc and the zinc corrosion is not unduly high. The loss of 323 milligrams of zinc from an area of 4·8 sq. in. is equivalent to 10·8 gms./sq. ft. This occurs in a period of two months under test which is probably equal to about three years of natural weathering. The normal hot-dip galvanised coating is about 2–2½ oz./sq. ft. or 56–70 gms./sq. ft. and has, therefore, under these conditions a probable life of 15 years.

It would appear from the results that, if a steel outer frame with an aluminium inner are despatched from the factory with two stoved coats of paint, no trouble need be expected from contact corrosion. Since, in practice, the frames receive further decorative coats of paint *in situ*: this gives additional protection.

Where the aluminium inner is in a galvanised outer frame, the corrosion will be very small even if neither are painted: here again, the practice of putting on a decorative coat of paint breaks the contact.

In view of the results quoted and the experience of several authorities, brass or bronze hinges should be avoided for aluminium frames. The aluminium/brass contact is exposed to the weather and local pitting of the section adjacent to the hinge can be expected.

The hinge is the most stressed portion of the frame, and for these reasons, an aluminium or zinc-coated steel hinge is preferred.

The inside fittings—e.g., handle and stay would appear to be of less importance since:—

(*a*) They are attached to brackets which may be of zinc-coated steel.

(*b*) The brackets are painted prior to attachment of fittings.

(*c*) The contact, being inside the house, is usually dry.

Some Observations on Laboratory Planning

By G. B. Contractor, M.Sc., Ph.D.

(*National Metallurgical Laboratory, Council of Scientific and Industrial Research, India*)

Very careful consideration must be given to the many factors involved in the planning of research laboratories. This is especially true when a chain of research laboratories is envisaged as in the case of India, where a commencement has been made on such a scheme with the building of a National metallurgical laboratory at Jamshedpur. Some aspects of laboratory planning were discussed by the author in recent issues of the Journal of the Council of Scientific and Industrial Research, India, from which the following abstract has been taken.

EFFICIENCY and convenience of operation coupled with the required degree of flexibility and adaptation to future needs, should always be borne in mind in designing a laboratory building. All laboratories are not alike, nor should they be. Even laboratory rooms should differ from each other in different parts of the same building. Properly planned laboratories should have, among other things, the greatest possible working area for a given floor space, a minimum number of places where dirt and dust can collect, non-corrosive hardware and fixtures, adequate services and outlets, easily cleaned well-lighted hoods, suitable general illumination, easily cleaned durable walls and floors, and safe construction and equipment.

Laboratory planning is far from simple. It is an intricate job both for an architect and the laboratory planner. Its success is fundamentally dependent upon close and sympathetic co-operation between the architects, engineers and the laboratory workers who later are to use the building. Before beginning the preparation of plans, the laboratory worker should know partly from his own experience, but still more from inspection of other laboratories or the study of their printed descriptions, just what features of plan and equipment should be embodied by the architect in his design. The architect, on the other hand, should study as completely as possible the manner in which the problems with which he will have to deal have been solved in other laboratories.

Planning does not merely consist in building the number and sizes of rooms and their inter-relation for convenience and service, but should also refer to the position of electrical conduits, piping and ventilating systems as well as lighting. It is said that in order to be utilised to the best advantage a laboratory building should be built round the equipment. This concept of laboratory planning is illustrated by some examples of the layout of spectrographic laboratories. This method of planning is generally applicable to all laboratory rooms. Preliminary floor plans should be made, all equipment detailed carefully and set, reset and further considered.

Whenever possible the building should be fireproof throughout, provided with forced ventilation and have ample space for library, administrative offices, and receipt and storage of chemicals and apparatus. Permanent equipment, plumbing, electric wiring and outlets, laboratory tables and hoods should be as simple, inexpensive and standardised such as to give satisfactory service.

Simplicity of plan is most desirable. In planning a laboratory, its size, shape, plane and equipment will also be governed by other factors such as site, surroundings, climate, purpose for which the building is to be used, probability of needed extension in the near future and the amount of money available for its construction, operation and equipment.

The planner must bear in mind that a well-built and completely equipped laboratory with the best arrangement of rooms and the most elaborate and complete working places and apparatus, will make a profound impression upon the minds of the inmates of the laboratory. It will develop habits of care, awaken interest in the work and permit the workers to develop both themselves and the science in which they are working.

Shape of the Building

The shape of the building, or the general layout of the buildings constituting a laboratory, will depend largely upon the factors mentioned above and render it impossible to select any one design as superior to all others. General location plans are shown of John Hopkins University, Harvard University, and Kaiser-Wilhelm Institute for Iron and Steel Research at Dusseldorf. They are examples of good arrangements. In a hot climate, a long narrow building which will permit of the free circulation of outside air, will probably be most comfortable for the users. In large cities where the site is costly, a high compact building would probably be most feasible. Satisfactory laboratories having the shape of letters E or H have been built, but if it becomes necessary to extend the building, neither of the above forms lends itself well to this purpose.

In view of the increasing interest in science, it is a poor policy to erect a building to meet present needs and make no provision for future extension. The site chosen must, therefore, provide for future additions without interference with other buildings. The plan that most easily and most inexpensively permits of enlargements of the building is the hollow square to which two projecting extensions may be added and the ends of those extensions later connected, forming a second court. Cornell University is a typical example of hollow square type of building. Dr. Contractor refers to and illustrates the floor plans of several well-known laboratory buildings.

Financial Limits

One of the most important and not infrequently disturbing factors in planning is the amount of money available for the construction of a laboratory. Where the laboratory planner has settled definitely the plan of a desirable, practical laboratory building, the question of cost at once arises. Where there is no restriction on the cost of the building and equipment, which is rare indeed, this problem is eliminated. But where the available money is limited to a definite sum and a budget is enforced, the planner is restricted both to the size and type of building and as to its future maintenance cost. It would, therefore, be helpful before the planner begins his work that the architect should furnish data for the cost per square foot or cubic foot of already completed laboratory building, so that the planner might find it possible to work out something definite as to the type and size of building within his financial means.

Lighting

Adequate light is required for all scientific work, observations to be made in every experimental investigation being at times of minute nature. According to the conventional idea, the building should be so arranged as to trap the maximum amount of north light. Recent studies have, however, shown that the traditional north light was not only disadvantageous for economic and scientific reasons, but failed to provide such good light as east and west fenestration with artificial diffusion. It was on this principle that the new research laboratories of the Imperial Chemical Industries at Manchester have been built. It is always desirable to expose a minimum of wall surface to the direct rays of the sun during the hottest part of the day. Hence, it is generally preferable to place a laboratory with its long axis in an east and west direction. South light is more intense and more constant than the widely varying illumination from east and west. It is reckoned that, for adequate lighting, laboratories should be lighted by windows which occupy 50 per cent. of the outside wall space above the working table height. The size, position and arrangement of windows are also matters related to architectural effects as also to natural light supply. The kind of window, and the number and size of panes of glass have considerable effect on the amount of light admitted through a given opening. The modern tendency in laboratory construction is to have windows practically continuous on the outer walls of the building in order to obtain abundance of natural light.

The artificial lighting requires careful consideration and each type of laboratory has its own lighting problems, for instance each balance requires its individual light. The general consensus of opinion, however, favours a uniform standard of lighting of 10–15 ft. candles throughout the laboratories. In lecture rooms, theatres and libraries, 15-ft. candles are considered satisfactory. For the general illumination of offices, store-rooms and corridors, intensities from 4–6-ft. candles are considered adequate. Fluroescent lamp shadowless illumination is suitable for laboratory buildings especially if they are air-conditioned. In air-conditioned rooms radiant energy must be kept to a minimum to ensure optimum comfort to the occupants. The high efficiency of the fluorescent lamp, combined with its relatively low radiant energy production, has favoured its use in laboratory installations in recent years.

Ventilation

In a modern laboratory, ventilation is an item of great importance governing the general layout of the project. Owing to the noxious gases evolved in certain types of work, special arrangements are necessary to carry off these gases, in addition to the usual provision of fume cupboards, combustion hoods and natural ventilation by windows and chimneys. In order to provide good general ventilation, there must be an adequate supply of fresh air. On the other hand, the amount of fresh air that can be admitted to a room is limited by the fact that draughts must be avoided. A large, well distributed air supply is, however, less likely to produce draughts than an air supply that is not so well distributed. Tables of general ventilation requirements for different types of building call for the removal of 30 cu. ft. of air per minute for each student in a school-room, each seat in a theatre or each worker in a shop. In general, however, standard ventilation allowances usually approach the physiological ideal, and trade standards are a compromise between the ideal and what has been found economically sound and reasonably satisfactory.

It is difficult to set up definite standards regarding the quantity of air to be withdrawn from different laboratory rooms, because of the wide variation in efficiency of air

movement through such rooms. Ceiling heights obviously influence the amount of air that can be withdrawn. While no definite quantities of air can be listed as needed for each worker in a laboratory, the available information indicates a supply of 200–300 cu. ft. per minute as necessary for each laboratory working space, which is usually of the order of 100–130 sq. ft. per worker in a research laboratory. The research laboratories of Messrs. High Duty Alloys, Ltd., for instance with a total floor space of about 45,000 sq. ft. is served by a system of forced ventilation which supplies air at a constant temperature to all parts of the building at the rate of six changes per hour, except in the chemical laboratories, where the rate is increased to 20 changes per hour by the air conditioning plant and augmented by an additional fume extraction plant.

It is generally recognised that air introduced in a building or circulated in space for the purpose of ventilation must be conditioned with regard to its temperature and cleanliness. Few, if any, modern ventilation or air-conditioning plants are installed which do not incorporate some means of air-cleaning. Broadly speaking, by air-conditioning is meant the application of methods of controlling the cleanliness, humidity, temperature and movement of air in buildings to make the air comfortable and healthful and to obtain incidentally indoor conditions that are conducive to efficiency and physiological comfort. In India where hot weather temperatures soar high and working conditions become intolerable in consequence, artificial air conditioning is most desirable in research laboratories which have to function throughout the year. If research work is to be carried out with maximum efficiency, it is considered essential by the writer that all future laboratories in the tropics, especially those devoted to research, should be air-conditioned, most of the recently built laboratories in England and America are provided with air-conditioning systems designed for both winter and summer conditioning, thus ensuring a constant and ample change of artificially purified air throughout the year.

When cooling is required, great comfort is ordinarily obtained by the method of reducing the humidity, for the reason that when air is nearly saturated there is more dampness of the skin and clothing than when it is relatively dry. On the other hand, conditions in winter are just the reverse; so it is desirable to have as high a humidity in laboratories as it is practicable for a given dry bulb temperature.

Floors

The choice of a suitable laboratory flooring material, especially for chemical laboratories, has always been difficult. The ideal material should have resistance to acids and alkalies, insolubility in organic solvents, freedom from indentation, resiliency, grip, washability, reasonable soundlessness and hard-wearing qualities. It is doubtful whether any one material will satisfy all the above desiderata, and the architect in collaboration with the planner must decide what material meets the majority of the needs of the individual laboratory rooms under consideration. Another important factor governing the choice of material is its cost. It is here that the planner is not infrequently forced to compromise between the best material, usually costly, and the material relatively less expensive and not fully satisfying his requirements. It is generally desirable that laboratory floors should have a certain amount of resiliency as such floors do not fatigue the feet of the workers.

Regarding the floor load, it may be mentioned in passing that floors intended to carry weighty machinery, pilot plant equipment and similar heavy loads should be designed to carry 2 cwt per sq. ft. For ordinary laboratory purposes, floors constructed for a live load of ½–1 cwt. are satisfactory. In the New Chemical and Metallurgical building of Purdue University many of the laboratories have been designed for loads in excess of 200 lb./sq. ft. The floors of the laboratory rooms in the Bell Telephone Research Building are designed for a live load of 150 lb./sq. ft.

Walls

Brick is the most widely used material for wall construction. The choice of the material primarily depends upon the cost. The other important considerations are appearance, strength and ease with which the fixtures can be built into walls. Furthermore, the acoustics of ordinary brick is generally good, and it is much less expensive than special materials such as cork tiles or patented wall coverings and plasters employed to obtain acoustic effects. Glazed or vitrified hollow tile is one of the materials that has been freely used in American laboratories in recent years. This material has good heat insulation properties but responds poorly to the acoustics unless special precautions are taken. If cost is of little consideration, glazed tile-finished or glass-faced walls in laboratories, especially chemical, offer certain distinct advantages over painted surfaces which are attacked by common chemical vapours and gases. In selecting a wall finish for chemical laboratory rooms, great care should be taken to see that the material is impervious, washable and resistant to the corrosive action of gases and fumes and that it should not either discolour, craze or crack with passage of time. Before discussing the question of wall materials further, it must be emphasised that where the amount of money available is limited, plaster provides a smooth surface which can be painted and repaired and thus kept clean as easily as any of the more expensive materials.

It is generally desirable to provide acoustic material for the walls and ceilings of library and offices to diminish extraneous and reflected sound. General experience indicates that the efficiency of research work is improved with the provision of acoustic ceilings in laboratory rooms as well. Such ceilings provide a very quiet and undisturbed environment for the work of the investigator.

Referring again to the wall material, it may be pointed out that the walls of rooms housing X-ray units should be lined with sheet lead or its equivalent of proper gauge for the maximum voltage to be used. Complete isolation of the X-ray units in a separate building is the best practice. It is even desirable that the whole of this building should be on one ground level and without superstructure. The windows should preferably be glazed with lead-glass. The walls are sometimes insulated by cavity walls filled with ray-absorbing materials. If lead is used, it may be as an interlining or supported by panelling, because unsupported sheet lead soon creeps and bulges, and is easily punctured. The best practice is to get all protective linings and devices periodically tested for efficiency. To protect against X-rays generated at 225 kilovolts, such as are commonly available from

industrial units, the concrete floor or ceiling must be about 1 ft. thick.

If it is not possible to provide a separate structure, a corner of the building is a desirable location for the X-ray laboratory. The outside walls need not be covered with lead if provision is made to keep the people away from that corner of the building. One method of protection used in million-volt radiography is to provide a pit where objects to be radiographed are brought.

Chemical Fume Hoods

Chemical fume hoods constitute a very important part of the equipment and, therefore, require careful study in the planning of a laboratory. Because of the corrosive, poisonous and obnoxious fumes, excessive heat and the ever present danger of fire, the hoods should necessarily be built of materials that will effectively resist these agencies. The materials usually employed are white or mottled glazed brick, enamel tile and other products. Furthermore, hoods should be scientifically designed and properly proportioned not only to take care of the correct amount of air uniformly distributed over the hood opening, but also to exhaust completely and effectively all of the light and heavy fumes from the entire chamber.

Various classifications of hoods, which merge more or less into each other have been made, such as individual and general or side wall hoods, open and closed, up and down draught, natural and forced draught, etc. The usual types are either of open-front or sliding sash type. The sash is glazed with laminated tempered glass or preferably with wire-glass for safety. In case of fire, one need only close the sash and shut off the emergency valve on the outside panel of the hood. Where the bulk of routine analysis for control of plant operations is required to be carried out, the long open-type hooded work bench is preferred to the sash type hooded work bench. It is important to bear in mind that the primary object of a hood is to enable a worker to carry on with ease and comfort a given reaction, while at the same time observing and controlling the process. It is reckoned that nine-tenths of the reactions evolving objectionable fumes carried out in a chemical laboratory, can undoubtedly be carried out in an open hood. A survey of the best modern laboratories indicates that for more advanced work and for general industry and research, an increased use of open hoods is being made.

The size and position of air outlets from the hood constitute a very important problem connected with hood construction. The uniformity with which air is withdrawn from the opening at the front of the hood is regulated in the first place by the size of the opening and by the shape of the hood, and also by the position of the outlet which leads to the exhaust fan and its relation to the slits or baffle openings from the hood interior. The group of substances which are lighter in density than air, under conditions in which they are liberated inside of a hood, is larger than the list of those heavier than air under the same conditions. Consequently a larger volume of air should, in general, be removed from the upper part of the hood. The ratio that has been found to be satisfactory in some laboratories is two volumes from the upper part of the hood to one volume from the lower. Another much-used method for withdrawing air from a hood is by means of a baffle-plate, made of some acid and heat-resisting material, placed across the back of the hood 2 or 3 in. from the rear wall against which the hood is placed with openings along the top and bottom. The opening, which leads to the duct connecting to the exhaust fan, is placed in the wall behind the baffle plate, and if the size and shape of this opening into the flue and the size and shape of the opening around the baffle plate are properly proportioned the hood will draw evenly.

Consideration must be given to the dimensions and arrangement of ventilation ducts especially if several hoods are exhausted by one fan. The ideal duct system where building conditions permit, consists of a direct connection from the hood to the blower and straight from the fan through the roof to the outside air. This method eliminates all unnecessary bends which tend to reduce the efficiency of the fan. When two or more hood sections are serviced by a single blower the duct system will be more efficient if the diameter of the main duct is increased at each branch.

Distribution of Services

A careful consideration should be given to the services to be fitted in a laboratory building as provision will have to be made at an early stage for supply pipes, floor drains and ventilation flues. Unless there is a continuous demand for a service, it is not desirable to provide it and increase the initial and maintenance costs. Use of portable cylinders of compressed gases, such as oxygen, nitrogen, carbon dioxide, etc., should be considered before installing a costly central distributing system. Sometimes it is advantageous to provide a service through a portion of the building only. For instance, in some laboratories oxygen is distributed at a few lb. pressure from a central system to glass-working, combustion and gas analysis rooms.

Attention may be drawn here to the fact that the distribution of services is essentially an engineer's job and the architect should work out the problems connected with this aspect of laboratory planning in consultation with an engineering organisation. When services are extensive, as in research and industrial laboratories, both the engineer and the architect should be consulted, and when they have worked out all the matters in common, the construction of the building can be taken up. The planners or the planning committee should act as co-ordinators.

The utilities commonly provided in a laboratory are : Water, city gas, electricity, compressed air, vacuum and steam. They should enter the building if possible near their source of supply or generating plants. The planner should provide one or more unassigned lines for future use. The basic principles governing the distributing systems and floor plans are easy approach to services, short supply pipes, absence of dead ends, and suitable size of lines. The question of exposed or concealed piping requires to be settled in the early stage of planning. Although there is a tendency in certain quarters to over-emphasise the desirability of providing concealed service lines in laboratory rooms so that they do not appear unsightly, the general practice is to have exposed lines owing to the belief that concealed services are a continual source of trouble and that exposed piping, properly arranged, avoids delays and expense in the detection and repair of leaks and breakdowns. There is some ground for the above belief as service lines buried in walls, floors or ceilings without means of access can be an unlimited source of trouble to a laboratory worker. In the tropics the damage done by white

ants and similar insects lends further support in favour of exposed services.

The increasing use of electrical energy is a conspicuous development in modern laboratories. It is, therefore, essential that adequate supply and distributing systems should be provided for immediate needs with ample provision for future extensions. One of the arrangements found suitable for A.C. supply in industrial and research laboratories is to bring high tension voltage line to the meter room and connect it with transformers to step down the current to suitable single-phase and 3-phase voltages by the 3-phase 4-wire system. Busway system of power lines is a convenient method of distributing this service to sub-distribution boards located at various places in the building, preferably outside the laboratory rooms. The phase wires should be colour coded with red, yellow and black, the neutral being painted white. Alternating current strengths of 110 and 220 volts are commonly utilised in laboratory buildings for lighting, motors, heaters, etc.

Direct current which is essential for electro-chemical operations, X-ray work, charging cells, arc lighting for micrography and many other purposes, is usually generated in the laboratory by suitable rotary converters. Where current strength required is small, rectifying devices or so-called battery chargers should be advantageously employed. They have usually a long service life and call for little attention. When constant currents are necessary at many different voltages, accumulators or storage batteries are essential.

The laboratory waste drainage system should be entirely separate from the sanitary drainage system. Ready accessibility to waste lines is one of the most essential desiderata of laboratory drainage. In some laboratory buildings, small vented settling tanks made of chemically resistant material, are installed on the main drainage line where it leaves the building, so that a certain amount of dilution of acids is effected before the waste enters the public sewage system. This also helps to recover mercury and similar heavy objects. It is essential that when the laboratory drainage system and the sanitary drainage are connected outside the building, the former should be protected from sewer gas by a master trap vented to the roof.

All drainage lines should be of adequate size with sufficient fall to provide gravity flow. Clean-outs or cleaning eyes should be installed at the bends, and at the end of long straight runs. Vented traps should be provided for each bench at the junction where the horizontal drain enters the stack. Floor drains should be installed in all laboratories. Chemical stoneware is the most widely employed material in chemical waste systems. It is chemically resistant and practically impervious and is further protected by a continuous dip blaze.

" Flexible " Unit System

The problem of service distribution becomes more difficult when the building is to be planned on the " flexible " unit system, that is, in such a manner that different sized working rooms could be obtained whenever required by the use of removable interlocking partitions. Such a system would necessitate provision of tappings for all services, including drainage, at individual unit distances. Although this system has a great utility value, particularly as applied to straight chemical work, its application in laboratories other than chemical has been overemphasised. Moreover the system would be of little usefulness in that portion of the laboratory, or in those working rooms where instruments and apparatus are to be permanently installed. Construction of a laboratory on the above lines requires an appropriately designed steel-framed structure which is usually more costly than the conventional brickwork. Furthermore, servicing of individual units would involve more expenditure, thus raising the capital cost to high levels. If it is not possible within the orbit of available funds to provide " flexibility " in the whole laboratory building, it is at least desirable to introduce it in that portion of the laboratory where it could be useful.

Work Benches and Gangways

The working benches provided with essential services to ensure convenience constitute the most important fitting in a laboratory. Utility coupled with service life under hard laboratory usage are the prime considerations. Although the arrangement of services, necessity or otherwise of having reagents on the bench, the size and shape of the bench, the arrangement of cabinet work, etc., vary according to the branch of the subject, there is a considerable degree of agreement in regard to some dimensions and equipment. In India where the average height of the worker is less than in Western countries, a bench height of 36–37 in. above the floor is satisfactory. In America and in European countries, the recommended height is 36–39 in. The top width of a double bench found suitable is 54–60 in., the wall bench being usually 30 in. wide. Titration benches are usually 30 in. wide and 32 in. above the floor. Ordinary balance tables when used with stools of usual height (24 in.) should be 24–30 in. wide and 32 in. above the floor level. It may be noted here that individuals differ with respect to the height of their eyes when standing more than they do when sitting, hence, the sitting position is most convenient for weighing. For microscopic work, a comfortable table height is 28 in., the variation being from 27–29 in. If a double bench of the usual 5 ft. width is provided for microscopic work, it is desirable to place a small shelf 6 in. high by 12 in. wide along the centre line of the bench for keeping dessicators. These benches should be so arranged that the windows are at the side and not facing the workers. Low benches 13 in. and 21 in. high are useful in photomicrography when using the microscope and camera in a vertical position.

Facilities for storage of chemicals and glassware should be provided in the work bench. It may, however, be pointed out that it is not desirable to store chemicals in cupboards beneath a bench, as an accident involving spillage of liquids may damage the contents of the cupboard. Some planners are in favour of open work benches, the storage cabinets and shelves being conveniently located behind the worker. When this arrangement is followed, the cabinet work can form a useful partition between benches. It also gives a measure of privacy to workers on individual benches without being completely shut off from the workers on adjacent benches.

General

All laboratories should be provided with at least one safety overhead water shower as well as with modern equipment for fighting small fires. " Foaming " and carbon tetrachloride extinguishers in usable condition should be kept at easily accessible points.

Raw linseed oil applied hot in a thin layer is still one of the best protections for bench tops when they get dingy. The oil may be diluted by an equal volume of turpentine.

It is desirable to provide main circuits of sufficient size to allow for 50–75% overload at the outlets originally installed. A 10 ampere capacity receptacle mounted on a standard box is a very convenient outlet for alternating current.

One electrical outlet for each 3 ft. of bench front is usually reckoned to be sufficient.

For distilled water-supply, tin-lined bronze piping should be used. Aluminium pipes have also been used in some laboratories.

Separate stores outside the main building should be provided for inflammable substances and acids.

Laboratories should be provided with a junk room. Many a piece of half worn-out apparatus has been resurrected from a junk room and put to good use.

Balances and other delicate measuring instruments should be protected from vibrations. This could be effected by providing independent piers running clear through floors for individual balances and instruments.

Unless air-conditioned, it is not desirable that the microbalance room should be on the outside wall. Humidity in excess of 50% is not desirable because it sometimes causes the microbalance to stick. The temperature should be of the order of 72° F. The room should be provided with instruments to record temperature and humidity. As in the case of the constant temperature room, the entrance to this room should be through a vestibule.

Administrative rooms should be near the main entrance. Staircases and lifts should be well arranged and distributed and should provide alternative means of escape in cases of fire or panic. The location of the main lecture theatre, which may run through two stories, should be considered in reference to its possible use on public occasions, and if such use is intended, private sanitary accommodation should be arranged.

The seating capacity of a lecture theatre is approximately calculated by dividing the area of the floor space in square feet by ten, and this quotient will represent the seating capacity of the room. It is reckoned that the farthest seat should be within 55 ft. of the lecture table. This arrangement will give good visibility of demonstrations and satisfactory audibility of lectures. Entrances should not be more numerous than are really necessary, as every external door facilitates a certain amount of inattendance.

Every laboratory should have a vault which is well constructed, has adequate size and is provided with regular bank vault doors. Provision of a small " first-aid " room is desirable. Similarly, a cloak room, lockers and a refectory should be included. Provision of air-raid shelters should also be considered in this atomic age.

Supply Position of Chromic Acid

CHROMIC acid is in very short supply, mainly due to the shortage of materials, particularly fuel and caustic lye, but also to labour troubles at the works of the manufacturers. We understand that the Board of Trade have the matter in hand and that, for the present, all exports of chromic acid and of bichromate, from which the chromic acid is made, are being held up so that all the output will be available for the home trade.

Supplies of the necessary raw materials have now been arranged and we are informed that this month the manufacturers hope to be producing over three-quarters of their normal output, and that the output may very shortly be brought up to normal. However, as all stocks have been used up it is estimated that it will probably be three months before supplies become normal. Electroplaters may, therefore, have to face a period of this order in which they will be unable to get sufficient supplies of chromic acid to maintain their solutions at the normal working strength. Firms are urged not to order in excess of their requirements. Although it is hoped that supplies will shortly become normal, it is obvious that any firms who now endeavour to increase their stock over that required to run the solutions will be tying up material which others urgently need. When supplies become normal, however, firms would be well advised to build up a small buffer stock.

In order to tide over the present emergency, the following suggestions are put forward :—

1. Care should be taken not to lose chromic acid by drag-out. Most chromium plants have a drag-out tank installed, in which the article is rinsed immediately after leaving the chromium solution. If such a tank is not available it should be installed at once—a plain steel tank is suitable. The chromium tank is always made up from the drag-out tank and not by the use of plain water.

2. Under no circumstances should chromium solution be discarded. If for any reason the solution is not working satisfactorily, it should be adjusted to the correct value. If the solution is high in trivalent chromium and iron, this difficulty can usually be overcome by working for some time with a number of clean anodes and a small steel cathode or if available a porous pot on the cathode bar. The latter arrangement prevents the deposition of chromium and therefore further conserves the chromic acid.

3. If supplies of chromic acid are no longer available for making up, either the level of the tank or the concentration of the chromic acid in the solution or both must be reduced in order to keep the plant working. The average chromium solution works at about 4–4½ lb./gallon, but it is quite possible to work the solution down to 1 lb. of chromic acid provided that the sulphate ratio is adjusted to the normal value. As chromic acid is worked out of the solution, therefore, it is necessary to remove the equivalent amount of sulphate in order that the solution should function satisfactorily. This may be done by one of three methods :—

(*a*) The addition of freshly precipitated barium chromate. A solution of barium chloride is made and a quantity of chromic acid (or bichromate) added. This precipitates barium chromate which on standing settles to the bottom of the vessel. The liquor is then poured off the precipitate, the vessel filled with water, shaken up and again allowed to settle, and the liquor poured off. This process should be repeated twice and the precipitate can then be added to the chromic acid bath, stirred up and allowed to settle.

(*b*) A somewhat simpler method is to add barium hydroxide directly to the plating solution, stir this in and allow to settle. This forms barium chromate in the

solution which precipitates the sulphate as barium sulphate.

(*c*) Calcium hydroxide or Vienna lime may be used instead of barium hydroxide.

It is not possible to estimate exactly how much sulphate will be precipitated by the addition of these reagents as the reaction is not entirely quantitative, a certain amount of the barium or calcium being precipitated as chromate. It is suggested that about 1 lb. of barium salts are taken to 100 gallons of solution. The operation is best carried out at a week-end, so that the solution may have plenty of time to settle out. After the reaction is complete a test should be taken to ascertain the amount of sulphate, and if this has been reduced to below the optimum an addition of sulphuric acid may be made to correct it.

4. Chromic acid should not be used for the dipping of brass and copper until supplies become normal. Chromic acid is manufactured from bichromate, and therefore it is also desirable to conserve supplies of bichromate as far as possible. Where other dipping agents can be used they should be substituted for these. If this is impossible, then sodium bichromate and sulphuric acid may be used for the chromic acid dip.

Note.—The secretary of the Metal Finishing Committee of the Ministry of Supply, Mr. L. W. Owen (Room 1033, Shell Mex House, Strand, W.C. 2), is considering the question of the best methods of conserving chromic acid and hopes to issue a revised version of their Memo No. 1 on this subject at an early date.

Reviews of Current Literature

Mechanical Properties of Metals

THE aim of this work differs from that of the author's two earlier books already reviewed in this journal. Thus it is not devoted exclusively to the exposition of a new theory, admittedly incomplete and presented for critical discussion, as was his "Unified Theory of the Strength of Materials,"[1] nor substantially a compilation of the main results of the author's own investigations, as was his "Deformation and Fracture of Metals under Static and Dynamic Loadings";[2] it is an attempt to cover systematically, in the light of the most recent information, the whole ground of mechanical testing, apart from detailed descriptions of particular testing machines, and to provide an up-to-date text-book for students of engineering and the science of metals.

In the first half (203 pages) of the book are given the bases of the theories of elasticity and plasticity, including an exposition of the phenomena of elastic and plastic deformation and fracture, the process of deformation as a whole, the effects of rate and temperature of deformation, elastic after effects, hysteresis, oscillation damping, etc. In the study of elasticity the mathematical methods of tensor algebra are described and freely used.

In the second half (218 pages) is described the present state of the main divisions of the science of mechanical properties of metals—properties indicated by the methods of static tension, compression, bend, torsion and tests on notched samples, the behaviour of materials under dynamic and oscillating loads, characteristics of hardness, and creep, and the basic laws of the effects of composition, structure, and physico-chemical factors on the mechanical properties of alloys.

Such matters as the electron theory of metals, the applications of quantum mechanics, and physical theories in general are outside the scope of the book.

There has been a tendency in the past to present mechanical testing to students as a relatively simple branch of engineering science, finalised except for slight modifications to testing machinery which might be introduced from time to time to facilitate operation of the apparatus or recording of the results. With this text-book, however, the student cannot fail to see that the subject is still in a state of vigorous growth and he will find much stimulating material if his interests are in research. It is written from the technological point of view, but it aims to formulate a scientific basis for further study, disclaiming what the author calls the pessimistic views of Bridgman and MacAdam on the impossibility of finding any general criterion of strength. The author has strong and refreshing opinions on various problems, and he develops them in a rational manner, giving reasons for amending and rejecting, where necessary, theories sometimes considered as established.

There appears to be no truly comparable work in English. It is reasonable to suppose that if a translation were available it might have a wide appeal and be a valuable addition to the literature.

By Dr. Ya. B. Fridman, All-Union Institute of Aviation Materials: Moscow, 1946; 424 pages, 32 roubles. (In Russian.)

1 METALLURGIA, 1945, **32**, 163.
2 METALLURGIA, 1946, **34**, 248.

Arc-Welded Structural Steelwork

1.—Stanchion Bases, Caps and Joints

THE design of efficient and economical arc-welded structures requires a sound knowledge of the process and the effects of its application at all stages of the work. There are numerous sources from which full information on the practical process of arc welding can be obtained, but a series of memoranda intended to amplify the less readily available information on a number of commonly occurring details and important matters arising in the design, fabrication and erection of arc-welded structural steelwork is in course of preparation by the British Welding Research Association.

The first of this series gives recommendations for the design, fabrication and erection of welded stanchion details. They are derived largely from the work of the FE. 13 Committee of the British Welding Research Association on Codes of Practice for Welded Building Structures; they have been drawn up following a detailed study of existing practice in this and other counties. Research continues to be carried out on subjects covered in this memorandum, and it may be necessary, at some later date, to revise these recommendations in the light of a more comprehensive and conclusive knowledge. This Memorandum T.17 is published as a Report with the Transactions of the Institute of Welding for April in the first issue of *Welding Research*, the new official organ of the British Welding Research Association.

The Iron and Steel Development Plan

Some Statistical Considerations

By Robert M. Shone

(*British Iron and Steel Federation*)

Any statistical discussion on the steel development plans must necessarily over-simplify the issues involved, said Mr. Shone in a paper he presented at a recent meeting of The Royal Statistical Society. Actually, the structure of the steel industry is very complex and varied. The stage at which steelmaking is separate from fabrication of steel does not come at any point which can be determined by a simple theoretical or practical rule. Its structure, therefore, must be flexible to meet varying demands and yet permit the maximum degree of large-scale mass production to effect the economics peculiar to large integrated plants. In his discussion, Mr. Shone gave a fuller statement of the statistical basis of certain important aspects of the iron and steel Plan, and gave an account of the progress made in carrying the Plan into execution during the first year following its consideration by the Government. He discussed these aspects at considerable length, and with the aid of tables and charts ; the discussion, in a substantially abridged form, is given in this article.

Demand for Steel

APPROXIMATE estimates of the probable future demand for steel were given in the industry's Development Plan which was published as a White Paper.* These formed the basis of the future capacity of the industry which was aimed at in the Plan. The total demand in the five years, 1950–55, was estimated to reach 16 million ingot tons a year, consisting of 13 million tons for home requirements and 3 million tons for direct export. The former figure, of course, includes the steel going into manufactured products for export. The broad basis of these figures was given in the White Paper, but fuller information may usefully be given on certain points taken into consideration in arriving at the estimates.

Long Term Trend.—The figure of 13 million ingot tons for home requirements was supported by the long period trend of home deliveries of steel prior to the war. The annual figures of home deliveries between 1900 and 1946 are given and although these show wide fluctuations from year to year, they indicate a strong upward movement during the period. Carried forward, without taking account of either of the two wars, these figures give a total of about 13 million ingot tons as the estimated annual requirement in the period 1950–55.

The sharply rising trend in the quantity of steel used in this country is related to the industrial development of the period 1900–46. The increase in the use of machinery in industry and agriculture, the growth of mechanical equipment in offices and the home, the rising volume of transport, the rapid development of the private car, and the great expansion in electrcal generation and distribution—all these factors combined to increase the use of steel.

Since this kind of development was common to most industrial countries, it is not surprising that the upward movement of steel consumption per head of the population is repeated in other principal industrial countries.

In view of the preponderance of heavy industry among the consumers of steel and the fact that the activity of the durable goods industries fluctuates more widely than production as a whole, changes in steel production and consumption prior to the war had a greater amplitude than the movement of general industrial production.

Future Home Requirements.—In forecasting the future requirement, it has been found best to consider the probable trend of demand for each of the industries given in the accompanying Table. In total, a home requirement of $9\frac{3}{4}$ million tons of finished steel has been arrived at, or about 13 million ingot tons. This estimate of 13 million tons compares with deliveries in 1946 of 11,132,000 ingot tons. During the course of 1946, however, as conversion of using industries neared completion, requirements rose and in the fourth quarter of 1946, steel was being delivered at the rate of $12\frac{3}{4}$ million tons per annum.

ESTIMATED DIRECT CONSUMPTION OF STEEL BY INDUSTRIAL GROUPS IN THE U.K.
(*Thousand tons*)

Industry	1924	1930	1935	1937
Shipbuilding and Marine Engineering	925	880	540	840
Building and Constructional Engineering	670	920	1,375	1,725
Mechanical Engineering	780	820	880	1,180
Electrical Engineering	100	120	180	235
Motors and Cycles	185	270	440	550
Aircraft	2	5	10	25
Railways and Railway Carriage and Wagon Building	600	565	610	760
Collieries	200	250	330	360
Hardware and Hollow-ware	350	500	685	790
Rivets, Bolts, Nuts, Screws, Chains, Springs and Miscellaneous Forgings	400	450	510	650
Wire and Wire Manufactures	300	300	400	500
Other	363	395	540	685
Total Finished Steel	4,875	5,475	6,500	8,280
Ingot Equivalent	6,500	7,300	8,670	11,040

NOTES.—The estimates for 1935 are in general based on data given in the Final Report of the Fifth Census of Production, but with an allowance in respect of firms excluded from the Census inquiry. The estimates for 1924 and 1930 have been calculated on the basis of data published in the 1935 Census Report. For collieries, the figures are based on deliveries of colliery arches, girders, etc.

The figure included under "Wire and Wire Manufactures is an estimate (based on the Census figures) of the quantity of finished materials passed on to the metal-using industries, with an allowance for exports and imports. To avoid double counting, wire and its products are, therefore, excluded from the consumption figures for the separate industries.

The final item "Other," includes four minor trades covered by the Census enquiry—tools and implements, cutlery, needles, pins, etc., and small arms—as well as an estimate for the following uses : tinplate used by canners making their own cans and by toy makers ; direct purchases of steel by gas, water and electricity supply undertakings ; tram rails ; direct munitions requirements ; direct purchases of steel for repair and maintenance work by the steel, and other industries, which do not use steel as a raw material but only for repairs and maintenance.

Iron and Steel Industry reports by the British Iron and Steel Federation and the Joint Iron Council, Cmd. 6811.

The year 1937, to some extent, was also one in which capital construction was at a peak level and no doubt contained some element of arrears carried over from the previous slump, and, to a limited extent, particularly on the constructional side, showed the early effect of the re-armament programme. Nevertheless, it is probably the best single year on which to base considerations of the future pattern of demand. In relation to 1937 it appears reasonable to estimate increases in mechanical and electrical engineering and in the motor and cycle and the aircraft industries, on the grounds of the contribution which these industries will be required to make in the future to increase exports. In engineering generally, increases should also result from the greater mechanisation of industry which will be necessary to achieve a higher level of industrial productivity in this country.

In projecting forward trends, regard must be had to the fact that in the decade 1950–60, population is expected to reach its peak and commence to decline. The impact of this stability and subsequent decline on the capital goods industries is an important factor, likely to moderate the extent of increases in steel demand. For a number of years, however, the effect of this factor may be largely offset by the maintenance of employment at a higher level than before the war.

Direct Exports.—Future direct exports of steel have been estimated at an average of 3 million ingot tons a year. They fluctuated widely in the inter-war period, the average over the ten years prior to the war being 2½ million ingot tons. Considerable expansion in recent years has taken place in the local production in many of our largest export markets. In Australia, Canada and India, expansions of capacity have taken place which exceed their pre-war imports. A doubling of the South African steel industry is planned, as well as important extensions in India and the Scandinavian countries. Production has been started in Turkey, and South American countries are also developing their steel production. In addition, America built new capacity of about 15 million ingot tons during the war period. In the five pre-war years, annual steel production in America averaged only 37 million tons, whereas present capacity is some 85 million tons. Against the increases in available capacity in relation to pre-war consumption, must be set the further prospective growth in world consumption of steel and the probable limitation of exports from Germany.

On balance, it appears unwise to budget on a very substantial expansion of direct steel exports, particularly under conditions in which British coal prices, now the major single cost factor in steel production, have increased relatively out of line with American coal. The estimate of 3 million ingot tons represents an increase of 51% on the 1938 exports of 1,985,000 ingot tons. In addition it may be possible to increase further the proportion of higher valued products in steel exports. Already exports of alloy steel bars and rods in 1946 were 17,577 tons, nearly four times the 1938 figure. Moreover, in the Steel Development Plan, special attention is being given to expansion of tube production in order to meet heavy export demands and to developments in other steel-finishing trades, for example, in tinplates and tyres, wheels and axles, where the product is of high value and the proportion of exports substantial.

Steel Imports.—In the inter-war period steel imports fluctuated widely, reaching a high peak level of over 4 million ingot tons in 1927, immediately following the general strike, but in many other years amounting to almost 3 million tons. The importation assumed in making the post-war plans is 590,000 tons. The tendency is for steel to be readily available in periods of less active trade when there is a surplus of world steel capacity. Imports in these years can be obtained in very large quantities, but in times when demand for steel is heavy, imports are difficult to secure, as at present, and the prices at which they are available tend to rise above the British home trade price. In formulating a long term plan, particularly for an industry in which fixed capital in relation to turnover is so high, it is important that imports should be planned on a basis that avoids temporary inflows of large surpluses from other countries just at the time when home demand is contracting and reliance being placed on a tonnage which cannot be secured in periods of peak demands.

Raw Materials

It is proposed that the capacity of the industry after rebuilding should be 16 million tons. Allowing, however, for some importation and also for the probability that demand on the average will fall slightly below the full figure estimated, calculations of normal home output, and therefore, normal raw material requirements, have been based on an average home production of 15 million ingot tons. This would represent a rate of operation averaging 94% of capacity.

Mr. Shone did not attempt to elaborate all the various considerations set out in the Development Plan regarding supplies of each of the raw materials, but concentrated on examining the future supply of scrap. Depending on the availability of steelmaking scrap will be the pig iron production required and the ore and coke requirements. The bulk of the scrap arising is suitable for steelmaking, but cast-iron scrap is used in foundries, and the inferior grades are suitable only for use in blast furnaces. It is important that the maximum use should be made of all the steelmaking scrap available in this country. Not only does this save overall in the fuel required for the production of finished steel, it also saves both home and imported ore and considerably reduces the total capital equipment required, per ton of steel produced. He discussed at considerable length the sources and circulating of scrap, and with other aspects considered the trend in supplies in order to assist in estimating what amount may be available in the period covered by the Plan.

Future Scrap Supplies.—In estimating the probable forward supply of capital scrap, it appears likely that an increase of about 35% over the pre-war supply might be reached by the years 1950–60. This would mean about 2,130,000 tons a year compared with an average of 1,570,000 in the period 1934–38. This estimate is rather below the figure indicated by a projection of the pre-war trend of capital scrap arising, but makes some allowance for the fact that the average life of steel in use may not continue to decrease at the same rate, and for the probable increase in the proportion of steel being used by industry in this country which will eventually find its way into export markets and not be available for scrap. The effect of the latter factor on capital scrap supply, however, is likely to be delayed and the strong upward trend in steel consumption in this country must inevitably have its effect in increasing the supply of capital scrap in the future.

As the analysis of the figures indicates, however, if the next few years are a period of high industrial activity and heavy demand for steel, the tonnage of capital scrap arising will for a time remain at a low level, apart from such tonnages as are secured from war demolitions. It is clear, for example, that the scrapping of cars and of plant generally cannot proceed quickly until new products are available to replace them. In the case of the steel industry itself, the development programme must largely precede the scrapping which will ultimately be possible. While, therefore, for a period of years, capital scrap supplies are likely to be very low, making it necessary to secure the maximum possible quantity of imports to supplement home supplies, taking a longer view the overall position is likely to improve.

Pig Iron Supplies.—On the basis of the estimate of scrap supplies, it is calculated that blast-furnace capacity for the production of basic and hematite pig iron of approximately 9,100,000 tons per annum will be required to balance steel furnace capacity of 16 million tons and provide 500,000 tons of hematite for iron castings. This is an increase in pig-iron capacity of 1,780,000 tons associated with an increase in steel capacity of 1,850,000 tons.

Progress of the Development Plan

The original Plan envisaged a total expenditure of £168 million at 1945 prices. The schemes involved were to be started over a five-year period and completed in seven and a half years. So far, schemes totalling £140 million have been worked out in detail by the industry and have been submitted to the Iron and Steel Board for final approval. Approval in detail has been given to schemes totalling approximately £90 million, and on these it has been possible to make a start, and they are in varying stages of progress at the present time. Certain further schemes have been generally approved by the Board, but there are still problems connected, for example, with housing, etc., which are preventing a definite start being made. With these, the total passed by the Board amounts to approximately £125 million. The balance of the schemes submitted are still under consideration by the Board.

The fact that approximately one-third of the total Plan has not yet been put forward in a detailed form to the Iron and Steel Board does not indicate any change in the overall conception. The need to spread the building over a period of years gives an opportunity of reviewing carefully the later schemes and as there must be envisaged a further stage of development, of considering them in relation to even longer term factors than are covered by the present Plan.

While the total new building submitted represents about two-thirds of the total building under the Plan, the increase in capacity resulting from the plans already submitted amounts to 86% of the total increase envisaged in the case of steel furnaces and 87% in the case of blast furnaces. The increase in capacity more closely corresponds to the ultimate increase because the more urgent schemes are, in general, aimed at expansion as well as increasing efficiency. Also, since the schemes are associated with a large scrapping of existing plant, much of which has still a useful life of a number of years, it will be possible, given flexibility in raw material supplies, to retain for a period some of this plant to achieve a high level of production pending the full completion of the Plan. Even when it is complete, if a capacity of 16,000,000 tons is inadequate, there would be the possibility of retaining for a time, some part of the capacity of 4 million tons which it is ultimately proposed to scrap and so permit an element of elasticity—given a corresponding elasticity of raw material supplies—in meeting requirements, if they diverge materially from estimated requirements.

Mr. Shone discussed the position of new building in some detail, and showed by table, the plant submitted for approval. In regard to steel furnaces it is shown that new building totalling 4,148,000 tons has been submitted against the total in the Plan of 5,835,000 tons. In the case of blast furnaces, the schemes submitted provide for 2,775,000 tons of new building compared with 4,750,000 tons in the original Plan. The schemes put forward on the rolling mill side are also tabulated, but it is important that the various new or modified constructions should be timed to provide quick results, and this aspect is discussed in the following notes.

Timing of Construction.—The timing of construction has generally, followed the line of priorities suggested as desirable in the original Plan. Priority has been given to a number of urgent schemes for developing output at existing plants where quick benefits would result. Indeed, some of the early benefits from the Plan will be realised during this year from new blast furnace capacity in South Wales, on the North East Coast, in Lincolnshire and Scotland, from the steel furnace oil conversion programme and from new steel furnaces, particularly at the melting shop at the Appleby Works in Lincolnshire.

Among the major schemes, first priority was indicated as desirable for the new South Wales steelworks and strip mill for the production of sheets and tinplate. The second major scheme which was indicated as particularly urgent was the new broad flange beam mill on the North East Coast, designed not only to give a highly efficient production of heavy structural material, but also to provide an important new type of product for the export trade. Of the new continuous billet mills which it was considered should be proceeded with urgently, the first was that at the Lysaght plant and this has already been approved and constructional work on the early stages of the scheme begun.

The phasing of the building plans has been worked out in detail and proposals for dollar requirements have been submitted to the Treasury. These involve a total dollar expenditure of approximately £15,000,000. This total is higher than the original sum of £9,000,000 estimated in 1945, owing to the higher prices of plant in America and to some readjustment made necessary by limitations of construction in this country. The total expenditure in dollars represents about 7½% of the Plan. Many of the items would not be obtainable in this country, but in the main, the expenditure is designed to accelerate the completion of the Plan. Broadly, the extra time required to complete the Plan, if dollar imports were cut down to very minor proportions, would be approximately four years. The loss of exports and the additional imports required if the construction period were lengthened in this way, would far more than offset the dollar expenditure involved in avoiding this delay.

Conclusions

No attempt was made to set out the benefits that may be expected to arise from the carrying out of the

Steel Plan. Estimates of the fuel economy resulting, of the degree to which the Plan will involve production in large scale units of optimum size and similar matters, were dealt with in the original Plan and actual results will show how these are progressively realised.

One important matter mentioned in the original Plan should, however, be referred to. This was the prospect of co-operation of the Trade Unions in enabling arrangements for a continuous plant week to be operated in steel-melting shops. Agreement on this matter has now been concluded and the new arrangements came into force on April 6th. This will have important benefits in increasing output from the plants and in enabling the overall efficiency of the industry to be increased.

Conditions for Producing Spot Welds in Deep-Drawing Mild Steel

INVESTIGATIONS have been carried out to examine the resistance welding of various materials in relation to the standardisation of equipment and procedure, with particular reference to the spot welding of mild steel up to $\frac{1}{8}$ in. thickness. A programme was arranged at a meeting of the F.R.I. Committee of the Welding Research Council in April, 1943, under the chairmanship of Dr. H. O'Neill and the report* recently published in *Welding Research*, prepared for the R.F.R. Main Resistance Welding Committee on the completion of the work of the F.R.I. Committee on Spot Welding of Mild Steel, deals with the relationship between welding conditions and the strength and quality of single spot welds in deep-drawing mild steel sheet, in thicknesses from 20–14 S.W.G.

Difficulties were experienced in obtaining suitable welding facilities and testing equipment, and the work was held up until August, 1944, when Joseph Lucas & Co. Ltd. offered welding and testing facilities, and Briggs Motor Bodies Co. Ltd. provided facilities necessary for macro-photography of selected specimens. It is noteworthy that the total number of single spot specimens welded and tested in each gauge of material approximated to 1,500, each weld being made under very carefully controlled conditions.

The work included a study of the effects of welding current, welding time, electrode pressure, and contact resistance of the material. The detailed results presented in the report provide data for predicting accurately the size and properties of single spot welds made with welding variables ranging between wide limits. A summary of the main results, given as recommended machine settings, is reproduced in the accompanying table and may serve as a basis both for standardisation of production welding conditions and for the standardisation of spot-welding machines.

SHOWING RECOMMENDED MACHINE SETTINGS

	14 S.W.G.	16 S.W.G.	18 S.W.G.	20 S.W.G.
Electrode tip diameter (in.)	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$
Electrode tip pressure (lbs./sq. in.)	10,000	10,000	10,000	10,000
Welding current (amperes)	12,000	9,000	10,500	7,800
Welding time (cycles, 50 cycles per second)	20	17	15	10
Weld strength (lb./ton)	1·65	0·98	0·70	0·49
Indentation (%)	$\leqslant^{10}$	$\leqslant^{10}$	$\leqslant^{10}$	$\leqslant^{10}$
Weld diameter (in.)	0·340 within ± 7% of average	0·253 within ± 4% of average	0·250 within ± 5% of average	0·180 within ± 4% of average
Weld strength consistency	70%	74%	75%	70%
Weld nugget penetration (%)				
Percentage change in weld strength at the recommended setting due to a 5% change in:				
Welding current	± 3·0	± 6·0	± 7·0	± 6·3
Welding time	± 1·3	± 1·5	± 1·2	± 0·8
Electrode pressure	0·0	± 0·1	0·0	± 0·1

* Hipperson, A. J., *Welding Research* (Trans. Inst. Welding), April, 1947.
† Brown, H. W., *Amer. Welding Soc. Jour.*, Sept., 1944.

Records have been taken of sheet indentation, splashing, weld-strength consistency, ageing, weld size, and the effect of each welding variable on these factors has been determined. The following summarised conclusions are applicable only to the particular material used for the tests, namely, 0·1% carbon, deep-drawing quality, mild steel sheet, in thickness from 20–14 S.W.G. inclusive.

Electrode Tip Size.—Electrode tip sizes determined to the nearest $\frac{1}{32}$ in. by the square root of the sheet thickness, are satisfactory for producing spot welds in mild steel in the thicknesses under consideration.

Spot Weld Strength.—Previous investigations† have shown that the strength of a single spot-welded lap specimen, when subjected to the tension-shear test, is dependent not only on weld size but also upon specimen dimensions. A constant specimen width of $1\frac{1}{2}$ in. was used throughout this work, in order that the results obtained might be capable of comparison without influence from this effect.

Subject to the effect of specimen dimensions, it can be stated that the breaking load of a spot weld is proportional to its diameter, and this is due to the fact that satisfactory welds made under conditions of the present tests failed, by tearing of the sheet and not by shearing of the weld. Only when the weld is very small, or possesses poor fusion, is the failing load approximately proportional to the square of the weld diameter. In this case, as would be expected, failure occurs by shearing of the weld in the plane of interface of the two components. The increase in strength of spot-welded specimens due to ageing for 90 days, is of the order of 10% maximum.

Welding Current.—Welding current is the most important and critical factor affecting weld strength and size. A 5% change in welding current at the recommended setting can produce a change in weld strength up to 7%; at lower welding currents, the change in weld strength is much greater.

The required current density at the electrode tip for producing "optimum" welds decreases with increase in sheet thickness, provided tip diameter is related to sheet thickness by the formula $d = \sqrt{t}$, the approximate relationship being: Current density × added sheet thickness = 24,000 amps./in.

Weld Time.—Welding time is the second most important of the main welding variables determining weld size and strength at the recommended machine settings. It is normally possible to select a welding time of sufficient duration so that any slight changes in welding time will result in very little change in weld strength. From an economic standpoint, however, it is a disadvantage in production work to use unduly long welding times, and for this reason, the recommended optimum welding time selected from the main graphs is such that

it is as short as possible, consistent with the production of good quality welds. Under these optimum conditions, a variation in welding time of 5% involves a corresponding variation in weld strength up to a maximum of only 1·5%.

Electrode Tip Pressure.—The optimum tip pressure for welding flat sheet has been selected with a view to obtaining as wide as possible a choice in the other welding variables, and at the same time avoiding the unduly high pressures which would result in rapid tip wear: 10,000 lb./sq. in. fulfils both the requirements, but it should be remembered that from the theoretical standpoint alone, a higher pressure is perferable, particularly in the case of the thicker gauges of material.

At the optimum machine setting, a change of 5% in electrode pressure produces a change in weld strength of only 0·1% maximum; this does not apply if welding currents lower than the optimum are used, when a much greater effect is apparent.

Splashing.—It is desirable that the ejection of liquid metal from between the components be avoided, if danger to the operator and excessive indentation of the sheet surfaces are to be minimised. Splashing is more dependent upon welding current than upon welding time, and occurs more readily at low pressures than at high pressures. The optimum welding currents recommended in this report are such that splashing is just avoided.

Indentation.—10% indentation is generally only exceeded if excessive splashing from the weld is obtained during the welding operation. As would be expected, high pressures produce more indentation than low pressures, but this is a marked tendency only when long welding times are used. Indentation is more dependent upon welding current than on time or pressure, provided normal machine settings are in use.

Polarographic Discussion Panel

THE Polarographic Discussion Panel, recently formed by the Physical Methods Group of the Society of Public Analysts and Other Analytical Chemists, held its first meeting in the Physical Chemical Lecture Theatre, Imperial College of Science and Technology, on Friday afternoon, April 25th. Dr. W. Cule Davies was in the chair, and 39 members and visitors were present. Three papers—viz., "Notes on Polarographic Technique," by Dr. G. Jessop, "Remarks on Polarographs," by Dr. W. Cule Davies, and "The Analysis of Brass-Plating," by Dr. E. R. Roberts, were read and discussed.

Dr. Jessop described some of the instrumental aspects of polarography, such as the measurement of current and potential, with illustrations of the various methods of determining the wave height from a polarogram. He discussed the effect of the lag due to recorder damping, the ohmic resistance of the circuit and of variations in the anode potential. Peculiar wave forms, sometime encountered when deoxygenating with sulphite in a cell using a mercury pool anode, do not occur with the various forms of external reference electrode, the merits of which were compared by the speaker.

The paper by Dr. W. Cule Davies was concerned largely with the desirable features to be incorporated in a polarograph. Dr. Cule Davies felt that means for the accurate measurement of the drop-rate, current and voltage should be provided and that damping, if used, should alter neither the magnitude of the current nor the observed half wave potential. He illustrated his remarks by reference to instruments produced both in this country and abroad. The speaker pointed out that a research worker needs an instrument of high accuracy, the mechanism and operation of which he should understand. He may also need to make modifications for various purposes. The Polarographic Discussion Panel may, therefore, serve as a useful link between such users and the makers. As regards reporting the results of polarographic investigations, the speaker urged that the characteristics of the dropping electrode should always be given, and that wave heights should be expressed in units of current.

In the bonding of rubber to cast iron, the latter must first be brass-plated. The nature of the plating is important, so that process control is imperative. Dr. Roberts pointed out the wastage which could occur during a typical method of analysis—viz., the electro-deposition of copper, followed by titration of zinc, which takes from 1½–2 hours. The development of a simple polarographic method enabled six bath samples to be analysed within half an hour, while plating could be stripped and examined similarly. Whereas the normal method of analysis employs some 50 ml. of sample, the polarographic method uses 1 ml. only. The use of small samples enables the cloudy bath liquid to be filtered, evaporated with hydrochloric acid and re-evaporated in minimum time. After suitably adjusting the metallic concentration, the solution is mixed with an ammonia-ammonium chloride base solution and examined polarographically. A simple cell incorporating an external reference electrode was developed for routine use and enabled results to be obtained by measuring the current at three predetermined potentials.

Each paper was followed by a lively discussion, resulting in the exchange of a considerable amount of information. Before the meeting terminated, the Honorary Secretary, Mr. J. T. Stock (Chemistry Dept., Norwood Technical Institute, Knight's Hill, London, S.E. 27) gave a brief indication of future plans, which include visits to laboratories using polarographic technique, as well as discussions and the reading of papers.

"Bristol" Helicopter Research

By designing and building a special spinning tower to test helicopter rotor-heads and blades, the Bristol Aeroplane Company has revealed a far-sighted policy which augurs well for the future development of "Bristol" helicopters. It is the only one in existence in this country.

On this tower, the height of which, from the ground to the rotor centre, is 50 ft.—at which height the ground effect on the largest rotor envisaged (i.e., 60 ft. dia.) will be negligible—rotor blades, together with their articulations and parts of the rotor hub, will be subjected to aerodynamic tests. In addition to proof loading and tests to destruction which may be carried out, all conditions of hovering flight will be investigated.

Motive power is supplied to the rotor by a vertical spindle, direct drive, 500-volt D.C. electric motor, one of the largest of its type in the British Isles. Transmitting a horse-power of 700 at 180 r.p.m. the motor can, however, be run at speeds up to 700 r.p.m. and at powers exceeding 1,000 horse-power.

Correspondence

Modern Methods of Gas Analysis

The Editor, METALLURGIA.
Dear Sir,

I was interested to read the article by W. D. Vint in your April edition on the above subject, and considered the author gave great consideration to the concise method of wording and layout. There is one small item I would like to point out :—

In the first column when calculating the hydrogen content, the figures are given :—

" H_2 is $(60{\cdot}7 - 52{\cdot}5) - (52{\cdot}5 - 38{\cdot}5) \times \frac{2}{3} \times \frac{90{\cdot}3}{40{\cdot}2}$ $= 1{\cdot}8\%$ "; it is clear that this is an error as the calculation gives a negative result, and I suggest that it should read as follows :—

$$(60{\cdot}7 - 52{\cdot}5) - (52{\cdot}5 - 38{\cdot}5)\tfrac{1}{2} \times \tfrac{2}{3} \times \frac{90{\cdot}3}{40{\cdot}2} = 1{\cdot}8\%.$$

In the reaction :—

$$2H_2 + O_2 \rightarrow 2H_2O$$

2 vols., 1 vol., 0 vol.

the hydrogen content is $\frac{2}{3}$ of the reduction in volume as indicated in the original article, whilst in the reaction :—

$$2CO + O_2 \rightarrow 2CO_2$$

2 vols., 1 vol., 2 vols.

the carbon monoxide content is one half of the reduction in volume and not the whole of it, as the author has assumed.

Yours faithfully,

Barley Lane, Romford, Essex.
May 27th, 1947.

RONALD P. MARSHALL.

The Editor, METALLURGIA.
Dear Sir,

Your correspondent is quite correct in his statement concerning the calculation of the hydrogen percentage. It seems that in the actual article, two mistakes have occurred in the line which reads : H_2 is $(60{\cdot}7{-}52{\cdot}5) - (52{\cdot}5{-}38{\cdot}5) \times \frac{2}{3} \times \frac{90{\cdot}3}{40{\cdot}2} = 1{\cdot}8\%$. Firstly, larger brackets should be so placed to make it clear that the result as a whole obtained from $[(60{\cdot}7{-}52{\cdot}5) - (52{\cdot}5{-}38{\cdot}5)\,\frac{1}{2}]$ is multiplied by $\frac{2}{3}$ and $\frac{90{\cdot}3}{40{\cdot}2}$, and secondly, the absence of the $\frac{1}{2}$ after $(52{\cdot}5{-}38{\cdot}5)$ which *was* present in my original manuscript and was possibly overlooked during the checking of the galley proofs.

Yours faithfully,

Ty-Glas Road, Llanishan, Cardiff.
June 5th, 1947.

W. D. VINT.

Production of Magnesium Alloy Castings

The Editor, METALLURGIA.
Dear Sir,

I have read with interest the very informative article on the above subject, by Mr. G. B. Partridge which appeared in your May issue. I would like to refer particularly to the section dealing with magnesium pressure die-castings.

It seemed to me that having perused this article your readers might be left with an impression that satisfactory methods for the production of magnesium pressure die-castings are not yet firmly established in this country ; such an outcome would be most unfortunate and the purpose of the present letter is to try and dispel any views of this character. Your contributor explains the difficulties in making pressure die-castings in magnesium alloys for instance in ladling the metal and in securing castings free from flux and oxide inclusions. For some of us at least these are, however, problems of the past and the processes worked out by the company with which I am connected give complete immunity from these troubles ; it is certainly not the case, as might be inferred from your article, that die-casters are still groping for a solution to these problems.

Mr. Partridge refers to the work of the Germans and Americans in terms which suggest that they have a considerable lead over us in this field. We have good reasons for declining to accept this opinion so far as it applies to production technique, quality of product and price.

It is true that the considerable demand in this country for magnesium pressure die-castings can only be partly satisfied at the present moment. The limitations on production arise, however, only from the difficulties of expansion, especially where the erection of new buildings is involved, and not from any shortcomings in casting technique.

Yours faithfully,

Prince Georges Road, Merton Abbey, London, S.E. 19.
May 29th, 1947.

A. J. MURPHY, Director, Stone-Fry Magnesium, Ltd.

The Editor, METALLURGIA.
Dear Sir,

I was pleased to note the interest shown by Mr. Murphy in that portion of my article which dealt with pressure die-casting in magnesium, and whilst it was not in my mind to discourage the use of magnesium pressure die-castings, since my article was of a technical nature, I was in duty bound to point to the difficulties which Mr. Murphy, in his letter, states that he has overcome. My company have produced many thousand magnesium pressure die-castings and it would seem from the information available, that we have been working on somewhat similar lines.

The reference to Germany and America was factual, and I feel that it would be doing Magnesium a disservice to encourage a demand in advance of capacity to produce. Demand and capacity should go hand in hand, and my confidence in the future of magnesium pressure die-castings is none the less because of that reservation.

In thanking Mr. Murphy for his contribution, I feel that the latter aspect of the case should be borne in mind.

Yours faithfully,

for The Birmingham Aluminium Castings (1903) Co., Ltd.
G. B. PARTRIDGE,
Production Metallurgist, Elektron Foundries.
June 9th, 1947.

ARRANGEMENTS have been made, with the approval of His Majesty's Government and the Danish Government, to hold an All-British Exhibition in Copenhagen in September, 1948. The Exhibition will be organised by the British Import Union of Copenhagen in collaboration with the Federation of British Industries, as was done in the case of the successful British Exhibition in Copenhagen in 1932.

The Iron and Steel Institute

Annual General Meeting Held in London

THE annual general meeting of the above Institute was held in the Lecture Theatre of The Institution of Civil Engineers on May 15 and 16, 1947, Dr. C. H. DESCH, F.R.S., President, occupying the chair. Following the acceptance of the Minutes of the previous meeting the President reported the loss by death of an Hon. Vice-President of the Institute, Signor On Senatore G. E. Falck, and an Hon. Member of Council, Dr. J. W. Donaldson, President of the West of Scotland Iron and Steel Institute, both of whom died in January of this year. The members stood in silence for a short time as a token of respect.

Welcome to Members and Visitors

The President extended a hearty welcome to members and visitors attending this meeting. He expressed appreciation for the good attendance, and hoped that the Institute would now be able to resume the international relations which were so important before the war.

Among the visitors were several members from Luxemburg, including M. Andrew Clasen, the Minister for Luxemburg, who is an Honorary Member of the Institute, and M. Aloyse Meyer, the President of the Luxemburg Institute and an Honorary Vice-President of this Institute. The representation from France included MM. Dupuy and Bastien, among others. From Norway was Mr. Muller, President of the Norwegian Metallurgical Society. From Sweden, Mr. Sven Fornander and Mr. E. von Hofsten were present. A number of Spanish visitors, among whom special mention was made of Senor Barreiro. From Czechoslovakia was Dr. Janicek, while Polish visitors included Dr. Balicki and Dr. Wrazek, who have been working in this country. Particular mention was also made of Professor Robert Durrer, from Switzerland, who has been especially helpful in the complicated negotiations made for the Summer Meeting the Institute is holding this year in Switzerland. The President announced that the Council had unanimously agreed to make Dr. Durrer an Honorary Vice-President of this Institute.

Report of Council

The President stated that the growth of membership of the Institute had been outstanding. Arrangements with the British Iron and Steel Research Association have now been completed, and the Joint Research Committees, which have been operating very successfully for some time, have been taken over by that Association. The Institute, however, will continue to undertake all the publication for them, and certain of the information services.

The Iron and Steel Engineers' Group, which was formed recently, has been very successful. The meetings have been exceptionally well attended, and at these large meetings the engineering problems of iron and steel works have been discussed. Mr. Cartwright, the Chairman of the Group, has been most active and efficient.

The Institute has been developing relations with the affiliated local societies and with a number of metallurgical societies on the Continent and in America. It has been possible to arrange for visits from one society to another, keeping up the connection and strengthening the ties between these various bodies.

The Institute is now inviting applications for grants from the Carnegie Research Fund. There will be two kinds of grant. There will be grants in aid of research, as hitherto, but the amounts will be increased so that the maximum amount of any individual grant will not normally exceed £250, and smaller grants will be awarded when suitable. It has been found necessary to revise the older arrangements on account of the increased cost of living in many areas where students go to work. It is proposed also to give one or two Travelling Carnegie Scholarships each year. The amount will vary in accordance with the requirements of each case, but will be generally of the order of £500, though it may be necessary on quite exceptional occasions to go even beyond that figure. These travelling scholarships will probably involve in most cases travel across the Atlantic, so that naturally a larger sum will be required than for the ordinary scholarships.

The arrangements for the Mond Nickel Fellowships have now been made and applications are invited by the Committee, which consists of representatives of the Company and of the five metallurgical institutes. The Fellowships will normally be of the order of £750 a year.

Presentation of the Bessemer Gold Medal

The Bessemer Gold Medal is the highest honour the Institute can award and on this occasion it was awarded to Sir William Larke. In presenting the medal the President referred briefly to Sir William's career up to 1919, when he was appointed Director-General of Raw Materials, which position he held until 1922, and went on to say: "From then until last year he was the Director of the British Iron and Steel Federation, and it is in that connection that most of us have been associated with him. Many will remember his work in the first world war, but this post which he held in the Iron and Steel Federation gave him one of the leading positions in connection with the iron and steel industry. We have always been delighted to carry on negotiations with Sir William Larke. He has also been a most faithful member of this Institute, and a most valuable Member of Council. It is therefore with particular pleasure that the Council, and I on their behalf, have the opportunity of presenting to Sir William Larke the highest honour which we can bestow, the Bessemer Medal." The President then, amid applause, handed the Medal to Sir William Larke.

Sir William Larke in expressing his gratitude to the President and the Council in particular for the great honour done him, outlined his many activities and interests in research from his early days onwards and considered the award a tribute more to those who have

been associated with him in the many tasks in various fields of endeavour. He particularly mentioned the late Mr. Mannerberg, to whom the industry owes much for the initial enthusiasm for research.

Many other names were mentioned by Sir William and one personal acknowledgement can be cited; this was to Mr. (now Sir) John Craig, who was the first President of the British Iron and Steel Federation with whom he worked in 1922. Of him Sir William said: "He guided my halting footsteps through the mazes of the industry, which after all, and quite naturally, was a strongly individualistic one. That individualism had to be overcome, and you now have an industry which has so organised itself, economically as well, as to be able to act as a unit in the national economy: and, when we remember that this industry is the foundation of all others, I think that there is nothing more important or more encouraging for the ultimate solution of our present difficulties than the fact that this great industry was organised and equipped on such a basis, recognising as it does, and as it has done for many years, that its own best interest is served to the extent that it can serve the national interest. That is one of the greatest factors for encouraging us to believe that we shall ultimately triumph over present difficulties."

The First Sir Robert Hadfield Medal

The honours which the Institute can confer have been added to by the Sir Robert Hadfield Medal. This is the first occasion the award has been made and since the medal is not yet ready, it was presented in token form. The recipient was Dr. J. H. Chesters, and the Medal was awarded to him in recognition of his work on refractories for the use of the iron and steel industries and of his share as co-author in preparing Special Report No. 37 (1946) on "The Influence of Port Design on Open-Hearth Furnace Flames."

"I remember him very well as a student in Sheffield University," said the President, "and I remember the work which he did then with Dr. Reeve. He held a Metropolitan-Vickers Research Scholarship, and did valuable work in the study of refractories. He has had experience, not only in this country, but abroad. He worked for a time at the Kaiser Wilhelm Institute in Berlin-Dahlen, and then in the United States of America in the University of Illinois. He has really an unequalled knowledge of the scientific side of refractory materials, and we had no hesitation in awarding him the first Sir Robert Hadfield Medal."

Andrew Carnegie Medals

The Institute has been able to resume the awards of the Andrew Carnegie Medals. The Silver Medal for 1945 has been awarded to Dr. Ing. M. Balicki for his memoir on "A Study of Work-Hardening and Re-annealing of Iron." The Andrew Carnegie Gold Medal for 1946 is awarded to Mr. H. Morrogh for his memoir on "The Neutralisation of Sulphur in Cast Iron by Various Alloying Elements." Mr. Morrogh has published a number of papers of very great value.

The Williams Prize

The Williams Prize for 1946 was awarded jointly to Dr. B. Jones and Mr. I. Jenkins for their paper on "The New Annealing Plant for Steel Strip in Coils at the Whitehead Iron and Steel Company, Ltd., Newport, Mon." The Williams Prize is given for a practical paper, and this paper gave an admirable description of a new and very fully developed plant which has been erected in recent times.

Changes on the Council

The following changes on the Council since the last general meeting were announced:

New Vice-Presidents: Mr. W. B. Baxter and Mr. H. H. Burton.

New Members of Council: Mr. D. A. Oliver, Mr. F. Saniter and Dr. C. Sykes, F.R.S.

Honorary Member of Council: Mr. T. F. Russell, during his period of office as President of the Sheffield Metallurgical Association.

Vice-Presidents: Captain H. Leighton Davies, Mr. J. S. Hollings and Mr. G. H. Latham.

Members of Council: Mr. R. A. Hacking, Mr. H. H. Burton, Mr. Desmond Lysaght, Mr. N. H. Rollason and Mr. D. F. Campbell.

Swedish Company for the Production of Atomic Power

Uranium from Shale Deposits

THE Swedish Atomic Committee, which consists of ten of the country's most famous technicians and scientists, has submitted a proposal to the Swedish Government, recommending the formation as soon as possible of a joint-stock company, AB Atomenergi, with a capital of 3,500,000 kronor (£241,000), of which 2,000,000 kr. would be contributed by the State and the remainder by Swedish industry. The first task of the company would be to design and build an experimental plant for the liberation of atomic energy, and later on a plant for the production of atomic power on an industrial scale would be erected. The Committee also suggest that, in addition to 2,000,000 kr. already proposed in the current State budget, another 2,000,000 kr. should be appropriated for research work to be performed under the supervision of a new institution, "The Atomic Research Council."

Swedish industry has already shown keen interest in the new company and is willing to subscribe its part of the share capital. Swedish uranium will be used, and it seems that practicable methods have already been invented for the extraction of uranium and graphite, to be used as a checking material, from Swedish shale. In the shale deposits in the central Swedish provinces of Närke and Västergötland there is a kind of node formation called kolm, in which the proportion of uranium is greater than in other shale. The plans aim primarily at building a plant at the Kvarntorp Shale Oil Works for the extraction of this uranium.

The President of the Swedish Committee points out that it is not only energy, in the form of heat, that can be produced at an atomic power plant—a large number of radio-active isotopes for medical, chemical, biological and other purposes will also be obtained. Among other things, they can be used for the treatment of cancer and diseases of the blood and the thyroid glands, etc.

The Hardenability of Steel

A Symposium Organised by the Technical Advisory Committee of the Special and Alloy Steel Committee and the Iron and Steel Institute

A discussion on a symposium on the above subject preceded the formal business of the recent Annual Meeting of the Iron and Steel Institute. It took place at the offices of the Institute, with the President, Dr. C. H. Desch, occupying the chair. This symposium, which is published as Special Report No. 36, contains the result of work of a sub-committee of the Technical Advisory Committee set up in August 1943, to consider the end-quench hardenability test, to examine the fundamental principles underlying it, and to survey a set of En steels by hardenability tests and correlate the results with the mechanical properties. The report of the work done is extensive, and here it is only possible to refer briefly to the reasons for setting up the sub-committee, its terms of reference, a résumé of its activities, its principal conclusions, and some aspects of the discussion following the presentation of particular sections of the symposium.

A SMALL mission of British metallurgists visited the United States and Canada in the spring of 1943, to discuss progress and to compare notes with their American colleagues on the extent to which the conservation of critical alloys in steel production had been achieved and could further be developed. This problem arose from the fact that some of the alloying metals in common use in peace-time were not available in sufficient quantity to meet the whole of the demands of the Allies. Alternative steels had to be devised, on the principle that the use of alloys in short supply should be reduced to a minimum, compatable with the maintenance of adequate mechanical properties in the steels.

The mission which was led by Mr. C. R. Wheeler, C.B.E., and accompanied by Mr. D. L. Burn as secretary, comprised two well-known members of the Council of the Institute, Dr. W. H. Hatfield and Dr. T. Swinden, who have since died, together with Mr. W. Barr, Mr. H. H. Burton, Mr. D. A. Oliver, Mr. F. Saniter and Major Senior. Arising from the discussions, two items which received attention were : (1) The possibilities of an end-quench hardenability test, based essentially on the proposals of Jominy and Boegehold,[1] either alone or in conjunction with the correlation with quenched bars proposed by Asimow, Craig and Grossmann ;[2] followed by the survey by Grossmann[3] on the effect of various elements on hardenability. (2) The extent to which boron could effectively be used to reduce alloy consumption by virtue of its influence on hardenability.

Some work on both subjects had already been done here, and certain tentative conclusions had been arrived at, but it became highly desirable that an organised research should be undertaken in order to assess the position which an end-quench hardenability test should properly occupy : (1) As a works check on uniformity and for assessing hardenability ; and (2) as a possible specification requirement.

Immediately on the return of this mission from the United States a Hardenability Sub-Committee of the Technical Advisory Committee was set up with the following terms of reference :—

(*a*) To standardise the conditions of carrying out the end-quench (Jominy) hardenability test, examine the effect of deviation from the standard conditions, and adopt a standard method of reporting the data.

(*b*) To examine the fundamental principles governing the test and recommend the best methods of interpreting the results of the hardenability curve.

(*c*) To survey a representative set of En steels by hardenability tests and correlate the results with the full mechanical properties.

United States Method of Interpretation of End-quench Hardenability Test

This symposium is concerned almost entirely with the end-quench test introduced in 1938 by Jominy and Boegehold: it will be profitable to outline briefly the method of carrying out the test and the method of interpretation which is apparently most favoured in the United States.

The test specimen consists of a cylinder, 4 in. long × 1 in. dia., with a flange at one end which is used to support the specimen in a quenching jig. The specimen is heated to the normal quenching temperature for the particular steel under test, held at that temperature for 20 mins., and transferred to the quenching jig, which allows the specimen to hang vertically and symmetrically over a water-jet orifice of standard diameter. The water is then turned on and a jet of standard "free" height impinges on the end face only. The steel, therefore, cools very rapidly at the quenched end and progressively less quickly towards the flanged end. When cold, the test-specimen is removed from the jig and two diametrically flats, 0·015 in. deep, are ground parallel to the axis. The surfaces of these are suitably polished and hardness determinations made at intervals along the length of the specimen.

The hardenability curve is obtained by plotting these hardness values against the distance from the quenched face. A shallow hardening steel will harden only near the quenched face, giving a curve which shows a rapid decrease of hardness at a short distance from the quenched face. A deep hardening steel, on the other

This Special Report No. 36) 430 pages) is available at the offices of the Institute 4, Grosvenor Gardens, S.W.1. Price 16/–. (Members 10/–).

1 W. E. Jominy and A. L. Boegehold : "A Hardenability Test for Carburising Steel," *Trans. A.S.M.*, 1938, **26**, 574.

2 M. Asimow, W. F. Craig and M. A. Grossmann : "Correlation Between Jominy Test and Quenched Round Bars," *S.A.E. Jour.*, 1941, **49**, 283.

3 M. A. Grossmann : "Hardenability Calculated from Chemical Composition," *Trans. A.Inst.M.M.Eng.*, 1942, **150**, 227.

hand, will harden over the whole length of the test specimen, giving an almost horizontal curve. Such hardenability curves have been widely used in the United States for the daily routine testing of successive heats of steel which are required to possess a hardenability falling within certain limits. This involves no more than a straightforward comparison of curves and requires very little fundamental knowledge of the test.

Detailed Investigation by Sub-Committee

In order to assess the degree of agreement to be expected between hardness values calculated from end-quench hardenability curves and those obtained in practice, members of the Hardenability Sub-Committee with Mr. D. A. Oliver as chairman, carried out a detailed investigation on fifteen steels. These were representative as far as possible of the different types of steel in the British Standard En series and were selected largely from Table 2 of B.S. 970–1942. The relationship between hardenability and mechanical properties constituted one of the most important aspects of the broad investigation, to both steel producer and steel consumer.

As stated by the Chairman in his résumé of the activities of the Hardenability Sub-Committee in Section IX of the Report: To achieve a balanced view of the subject, which appeared controversial, it was necessary to ensure that groups of British workers conducted their work independently but with periodic opportunities for discussion and comparison of results. Consequently, a measure of desirable overlapping has occurred between the separate reports and papers which have been presented. Crafts and Lamont of the Union Carbide and Carbon Research Laboratories, Niagara Falls, have kindly contributed their early and extensive researches on actual British engineering steels to this first British symposium devoted entirely to hardenability. It is only fair to record that the authors agreed to delay publication in order to ensure informed discussion of their work.

The first task was to standardise end-quench testing procedure and for this purpose the test has been experimentally re-examined. Following the lead by the United States a linear scale of distance was adopted, but the more rational decimalisation of distance was adopted rather than a scale of sixteenths. In the interests of precision hardness testing, Vickers diamond pyramid testing machines were preferred to the less readily available Rockwell machines, and were considered more accurate for research purposes. Later the Sub-Committee realised that for practical purposes either type of hardness testing machine would be adequate, and thus both methods are now permitted by the T.A.C. Standard Test Procedure. The former method has, however, been more generally used.

Jominy's original measurements of rates of cooling at different points along the length of the end-quenched specimen were made on a case-carburised bar of 2% nickel steel. As it was thought that these cooling curves might not be representative of other types of low-alloy steels, fresh measurements were made by Russell and Williamson on a number of steels of various compositions. This work has shown—with the exception of the silicon-manganese and silicon-chromium steels—that all the low alloy engineering steels tested can be adequately represented by one characteristic set of cooling curves. There are differences between these cooling rates and those previously regarded as standard, but a more recent investigation in the United States has confirmed the results presented here. These results have been used in all calculations concerned with attempts to correlate Jominy test data with hardness traverse test results on quenched bars.

A major proportion of the general activity has been concerned with studies relating the end-quench hardenability characteristics with the observed hardness across the section of oil-quenched bars of different diameters. According to the simple theory first proposed by Jominy, and later extended by Grossmann and his co-workers, it should prove a comparatively straightforward matter to estimate the cross-sectional hardness variation curves for oil-quenched bars of specified diameter, given the end-quench curve of a representative sample. As described in Section VIA, however, early attempts to correlate measured and predicted hardnesses gave rise to a mass of conflicting data and revealed many complicating factors. For example, it was noted that the calculated curves of cross-sectional hardness variation were generally flatter than the more V-shaped curves obtained by direct measurement on test-bars.

An investigation of hardenability variations within bars of large section was carried out by Bucknall who demonstrated that the hardenability variations were associated with certain zoning effects revealed by macro-etching. This line of reasoning was extended by Allsop and Steven, who showed that the difference of shape in cross-sectional hardness curves can be quantitatively accounted for by the hardenability variation noted by Bucknall. A significant conclusion to be drawn from this work is that the underlying theory outlined in the introduction can be regarded as substantially correct. The assumption that the "half-temperature time" is a satisfactory criterion in cooling-rate investigations has not been supported by evidence brought forward by Jones and Pumphrey, but the error introduced is considered small.

Many investigations have shown that a heavy burden of test work has to be undertaken if the effects of the unavoidable variations in hardenability are to be mitigated, and a serious problem arises in endeavouring to make reliable predictions from a single end-quench test observation. The more the simplicity and directness of the single end-quench test is assailed by the need for multiple testing, the less attractive the test becomes and the more costly and difficult is the securing of reliable predictions and assessments. A good correlation between the hardnesses of actual bars and limited end-quench test characteristics was nevertheless possible with oil-quenched and tempered specimens. In most cases the agreement was greater as the tempering temperature increased.

As part of the programme of research, individual bars were tested at many positions for end-quench performance and the work was extended to include the whole product of one ingot and, ultimately, the product of a single cast of steel. The information obtained indicated that large differences in hardenability may arise within a single cast. It is, therefore, necessary to conclude that no single end-quench hardenability curve can be regarded as sufficiently representative of the hardenability of a given cast or ingot or even, in some cases, of a single bar of steel. The steels used for these investigations were of normal satisfactory commercial quality and were drawn from many sources. The above conclusion is in sharp contrast to the view accepted by some metallurgists in the United States that a given cast of steel has a characteristic hardenability and that, with this as a

basis, commercial transactions can be regulated. A considered view is that a cast of steel under the best possible conditions can only be adequately represented by a hardenability band based on a large number of individual tests.

Leaving now the variation within a cast, it is necessary to consider the variation which occurs from cast to cast of steel of the same nominal specification and where fluctuations in alloy content and small differences in carbon content and grain-size are known to occur. The spread in end-quench results has been summarised in individual papers by Allsop and Bardgett and in miscellaneous information contributed by other members in one of the reports issued by the Sub-Committee. A conclusion is that steels conforming to chemical and mechanical specification requirements can nevertheless show wide and serious differences in response to end-quench testing. This would tend to emphasise the need for caution in rejecting or accepting steel merely on the basis of hardenability.

Inquiries along this line of thought were designed to elucidate the relation between hardness in the oil-quenched condition and the mechanical properties in the quenched and tempered condition. This aspect is dealt with in a joint report summarising investigations on the hardenability and mechanical properties of a series of British standard engineering (En) steels. The subject has also been dealt with from particular points of view in papers by Crafts and Lamont, Cooper and Allen, Honeyman, and Allsop. These researches enable conclusions to be drawn which are substantially in agreement. They support the view that full hardening gives optimum mechanical properties and that, as the hardness in the quenched condition decreases, the yield ratio and Izod impact value in the fully tempered condition decrease for a given value of the maximum stress.

This work has confirmed the already well-known fact that heat-treated bars in the larger sizes which satisfactorily pass mechanical-test requirements are not fully hardened by oil-quenching although the as-quenched hardness is adequate. The largest bar diameter of many of the B.S. En steels which can be fully hardened on oil-quenching is surprisingly small and considerably less than the diameters in which the steels are recommended for service.

The classical investigation by Grossmann on the effect of chemical composition and grain-size on the hardenability of steel, together with his simplified rules for hardenability calculations for specified alloy contents, have been re-examined experimentally by Glen, who has repeated and extended much of the earlier work on this subject. Glen has shown that the effects of alloy additions do not necessarily follow a linear law and also that the effects are not satisfactorily represented by multiplying factors. Again the conclusion was reached that if the necessary complicating factors are introduced the simplicity of Grossmann's approach is largely lost.

The effect on end-quench hardenability of the austenitic structure existing at the moment of quenching has been dealt with by Jones and Pumphrey ; they showed that if there were undissolved carbides present, then the amount and condition of the carbide remaining out of solution would affect the end-quench hardenability curve.

The investigations presented in the Symposium have clearly shown that the Jominy end-quench hardenability test is a useful research technique capable of yielding illuminating data on hardening phenomena in steel. Its direct application has shown that steels of the same type which satisfactorily meet mechanical requirements might yet possess widely different end-quench hardenability characteristics. Nevertheless, as indicated earlier, when dealing with the relation between as-quenched hardness and mechanical properties, if two steels of the same type but of different hardenability are heat-treated in sizes which result in significant differences in the hardness developed by quenching, then, on subsequent tempering, superior mechanical properties will be developed by the steel of higher hardenability.

It has been suggested that it would be advisable to introduce hardenability bands for each of the different B.S. En types. It was clear, however, that, with the hardenability variations which occurred between different samples from the *same cast* of steel, it would have proved difficult to specify hardenability bands for *different casts* of the same steel which would have been narrow enough to restrict significantly variations between different casts. Additional difficulties would have arisen in legislating for the selection of typical test-specimens which, when end-quenched, would have been adequately representative of the hardenability of a given batch or cast of steel. Nevertheless there has been no intention to dismiss lightly the subject of hardenability control, but the way is not clear to make easily applied and reliable recommendations which satisfy both steel user and steel maker. The possibility of specifying hardenability limits for low-alloy steels will undoubtedly loom large in future deliberations.

It is also necessary to investigate factors, whether of composition or of steelmaking practice, which favour variation in hardenability within a cast of steel, with a view to bringing these factors more completely under control and eliminating, as far as possible, transverse or longitudinal hardenability variations in the material when rolled to billets. Further work could profitably be devoted to the influence of cast and forged structures in steels of the same average composition. The extension of these researches to carbon and alloy tool steels is also likely to prove a useful and stimulating field of inquiry, since these materials are commonly employed in circumstances where as-quenched hardness is a criterion of serviceability.

The correlation of mechanical properties with different types of micro-structure and hardenability performance will probably assist in the interpretation of some of the phenomena at present incompletely explained, and also indicate to what extent the mechanical properties of alloy steels are characteristic of the particular constituents of the steel, rather than its hardenability. Apart from these problems of immediate practical import there are others of a more fundamental nature awaiting attack.

Principal Conclusions of the Hardenability Sub-Committee

An important and difficult task of the Sub-Committee has been to provide a summarised statement of the information to be derived from the end-quench hardenability curve. This statement, meticulously qualified in view of the confusing character of some of the evidence, is presented in Section VIII of the Report, and is agreed upon by all the members of the Sub-Committee. Opinions freely expressed by authors in individual

papers are not necessarily endorsed by all these members. The twelve conclusions contained in this section fall readily into four groups and are given as follows :—

Reproducibility of End-quench Hardenability Curves

1. The end-quench test is capable of yielding satisfactory reproducible results provided that the material tested is homogeneous.
2. The results of an end-quench test are not appreciably affected by small changes in the testing conditions.
3. End-quench curves determined on different samples of bar, forged or rolled from the *same ingot* to approximately the diameter of an end-quench test-specimen, generally show only small differences.
4. End-quench curves determined on different samples of bar, forged or rolled from *different ingots* of the same cast to approximately the diameter of an end-quench test specimen generally show only small differences.
5. A marked variation of hardenability may exist across the section of a bar.
6. The end-quench hardenability of a steel may be slightly affected by variations of the structure before quenching.

Hardenability and Chemical Composition

7. A wide variation in end quench hardenability may exist between different casts of steel produced to the same specification.
8. The hardenability of a steel cannot always be calculated with satisfactory accuracy from a knowledge of the chemical composition and grain size.

Prediction of the Hardness of Quenched and Quenched and Tempered Bars from Hardenability Tests

9. The hardness traverse curves of an oil quenched bar cannot be derived consistently with adequate accuracy from a single end quench curve.
10. The hardness of a quenched and tempered bar may be derived with satisfactory accuracy from an end-quenched and tempered test-specimen.

Hardenability and Mechanical Properties

11. The combination of mechanical properties obtained from steel that has been quenched and subsequently tempered in the range 500°–650° C. depends on the hardness developed by quenching, but there are serious difficulties in the way of interpreting end quench curves in terms of the ability of steels to attain a required combination of mechanical properties.

Transformation—Temperature Ranges

12. The transformation temperature ranges of steels during continuous cooling can be determined approximately from a series of interrupted end-quench tests.

General Observations

The co-operative British work on end-quench hardenability tests has to a limited extent confirmed that conducted in the United States of America, but it has also shown that deductions drawn from an end-quench curve may be seriously in error.

The end-quench test certainly indicates whether a particular test-flat has equal, higher, or lower hardenability than another : any interpretation beyond this point, however, involves the assumption that fully representative material has been tested and, where untempered test-specimens are concerned, this may often be unwarranted.

The local variations of constitution within a cast of commercially homogeneous steel are associated with major variations in end-quench hardenability, and no single curve can be regarded as representative of the hardenability of a given cast. Without considerable additional testing, which would rob the test of its principal virtue of simplicity, it is therefore impossible to obtain from end-quench curves any satisfactorily exact quantitative deductions regarding the response of a particular cast to hardening. A further difficulty in making accurate predictions from an end-quench test is the difficulty of selecting a satisfactorily representative value for the intensity of a given quench. Clearly, therefore, a cautious and critical approach is needed when considering the end-quench test as a possible specification requirement.

The chemical and structural variations, and possibly other variables as yet unidentified, which exert such a large effect on quenched but untempered steel, are of little importance when viewed from the aspect of the hardness of a constructional steel in the hardened and tempered condition. It has been found that the hardenability curve obtained from an end-quenched and tempered test-specimen may therefore be used to forecast with adequate accuracy the hardness of a steel quenched and tempered to hardness values of less than about 350 Brinell.

It should be borne in mind, however, that the test is concerned only with hardness, and extreme caution is essential in drawing inferences regarding other mechanical properties. The test should, therefore, be regarded as a possible preliminary selection test and not as a means of demonstrating the suitability of a steel for a given application.

Finally, it is necessary to emphasise to prospective users of the end-quench test that, although the test undoubtedly has useful applications of a qualitative nature, its successful application as a quantitative test requires a full appreciation of its potentialities and limitations.

Discussion of the Symposium

Mr. D. A. Oliver, Chairman of the Hardenability Sub-Committee, in the course of a general introduction of the Report, said it is difficult to re-create now the atmosphere which prevailed at the time the mission was formed. He definitely felt that this test might provide a short cut which would help us in our fight to save ferro-alloys. Ships were going down laden with expensive ferro-alloys which could not in all cases be replaced, and time was an important factor, so that any short cut which held promise acquired what would otherwise have been a quite undue importance.

The twelve conclusions contained in Section VIII fall readily into four groups, each of which will be briefly introduced by a separate speaker, who will discuss the conclusions, enlarge on their significance and point out the pertinent features of the papers on which they are based. After each introduction, discussion will be invited on the conclusions and the individual papers relevant to them. By this method the Sub-Committee hopes to obtain the advantage of a discussion on the widest possible basis, and the benefit of new ideas and points of view to assist it in future work.

Mr. C. R. Wheeler (Chairman of the Mission to North America in 1943): As is natural in times of stress, there was a feeling on the part of some people in Britain that the industries in America were being perhaps rather more wasteful than they should be; on the other hand, there was no doubt a feeling on the part of certain people in America that the industry in England was also being a little more wasteful than might be. Accordingly, it was decided that a party should go and discuss with the Americans exactly what we were doing in the whole range of war production as applied to alloy steels, and so we set off.

Remarkable success was achieved in the spirit in which the discussions were held. Naturally there was controversy, and this particular subject of hardenability, I may say, produced an active degree of controversy. Notwithstanding the different points of view, a joint report was produced, and I think it worth while to quote from this report, a section of which had the effect of giving birth to this Symposium. Under the heading of "Recommendations," the report said: "That the extended study be continued in Britain to correlate hardenability with physical properties."

The broad conclusions of this joint Anglo-American team were that America had gone further in conservation by means of the analysis of alloy steels as applied to the war effort. The NE steels as a whole contained less alloying elements than the British equivalent, the En steels. On the other hand, on the careful examination which we made we found that other methods of conservation of alloys as applied in this country were at the time more effective than those applied in America, with the broad result that, taking the actual usage of ferro-alloys to achieve a given requirement, it was broadly "as you were."

The main point to be settled between the two countries was how effective were the measures applied. You are all aware of the very great importance attached at that time in America to hardenability and the Jominy test. The Americans were keener on cutting down in terms of the final specification of alloys than we were. However, the result of the somewhat lengthy discussions was a very high degree of unanimity in approach.

This work which has been done and this discussion to-day form another link in Anglo-American metallurgical co-operation, which was perhaps one of the most decisive factors, if not the most decisive, in the defeat of the Axis. We all know what benefits are obtained from the free interchange of opinion and view, particularly on a practical basis. I wish to conclude by recording a real sense of gratitude to the Institute on the part of those of us who feel strongly the need for the maximum of international, and particularly Anglo-American, co-operation in the metallurgical field.

Discussion on "Reproducibility of End-quench Hardenability Curves"

Dr. W. Steven introduced the discussion, and summarised the information given in the relevant sections of the report.

Mr. T. M. Service: The hardenability of steel is rather a wide subject. It seems to me, in reading through all these papers, that there are one or two points which have never been investigated. First of all, we are told that a commercial steel was used. Are we satisfied that the commercial steel which we are using is the best for the purpose of a scientific investigation? The second point is the temperature for rolling. Were all these bars rolled at the same temperature, or were there differences in the temperature of rolling? Another point which it seems to me that the Sub-Committee have not taken into account is that no time is given for the mass effect. They have just given it a certain time, but they do not say what. They have heated it to 850° C. or 870° C. or whatever it may be and then hardened, but what about the change which takes place in the inside of a mass? It is all right for a 1-in. bar, but when you come to a 4-in., 8-in. or 24-in. bar, what happens then in the inside of the bar.

One question which seems to have been neglected is that of tempering after hardening. Most steels have a range which is called the fibre range. No indication is given in regard to any of the steels dealt with, in the testing for mechanical qualities, of what the fibre is in the particular steel investigated. That can easily be found out by experiment, and most people who have to heat-treat steel find out this fibre range and treat the steel within that range.

Mr. E. H. Bucknall emphasised the status of the hardenability test as carried out according to the procedure recommended in Section Ve of the Symposium as a means of proving or disproving the uniformity of a billet or other piece of steel across the section. Since the completion of the work described in Section Ve, that method of investigation has been used in the Mond Nickel Company laboratory in the investigation of the variation in hardenability of quite a range of British En and American NE steels. The examination of these steels amply confirms the impression given in Section Ve that variation in hardenability occurs to an important extent in commercial steels purchased in the ordinary way.

Mr. G. Meikle suggested that quite a number of the variations found for which no explanation is given may be connected in some way with retained austenite. In the paper by Pumphrey and Jones, for instance, he suggested that the variation in hardenability between two similar steels, varying only in carbon, is due to the size of the carbide particles out of solution; but thought a simpler explanation would be that the higher carbon steel gives more retained austenite, and therefore an apparently lower hardenability. He suggested that these two steels might be re-examined after a sub-zero treatment.

Dr. J. H. Whiteley: The test itself is a very simple one, but it raises a large number of very difficult questions and problems. The main effort of the Sub-Committee was to find what relation the hardenability test had to works practice, how far it could be relied upon in judging the hardenability of a piece of steel; and there I think that they have done an excellent piece of work. I have nothing but praise for it, and very little in the way of criticism to offer. I have a few remarks to make, however, on the hardenability curves and their shapes.

He was surprised to find that very little mention is made of the S-curves. I think that Mr. Glen is the only author who refers to them. Dr. Whiteley dealt with the S-curve as it relates to the hardenability of plain carbon steels and gave several examples. On examining the curves of the plain carbon steels in the Report, an interesting point is that the steeper that curve, the more pronounced the "knee" in the curve, the more pronounced is the hardenability. There are several examples given in the paper, and they all show the same thing. It means that with steels of the same analysis there is a difference in the length of time for which the austenite is retained at 350° C. If that assumption is correct then the S-curves want more examination in relation to the various Jominy tests. That is a very difficult problem, which Mr. Russell might like to undertake. It is a mathematical matter. I have a feeling that the S-curves should throw a good deal of light on the shape of the Jominy curve.

Mr. H. H. Burton: Dr. Steven referred to the difference between different ingots in the same cast, and different pieces of the same bar. I wonder whether they were always related to the position of the said bar or billet in the ingot, and also whether the possible effect of different amounts of hot-working reduction was taken into account. I wonder also whether all the bars were produced by a uniform method; were they all rolled, or were some of them forged? From the experience that a number of us had during the war and at other times with gun steels, it is not surprising to find that a billet from the same ingot might show different results according to whether it was produced in its final form by forging or by rolling.

Dr. F. W. Jones: On the question of retained austenite,

which has been raised by previous speakers, and particularly with regard to the steels investigated in the work described in the paper by Mr. Pumphrey and myself, I feel that the only influence that retained austenite is likely to have on the Jominy hardenability curve is likely to be in the hardness at the quenched end of the bar. Further along the Jominy bar the softening is due to the transformation from austenite to ferrite and carbide at a fairly high temperature, and that is largely what determines the hardenability of the material. All that process is over before the question of the amount of retained austenite arises, and so it is unlikely to have very much influence on the hardenability of the steel.

Dr. W. J. Wrazej: It is well known that different casts of steel with similar compositions are liable, when heat-treated, to show different mechanical properties, as has already been mentioned in this discussion. This has been demonstrated in examples of carbon tool steels and plain carbon constructional steels by F. Rapatz and myself. Samples quenched at 780°, 830° and 880° C. showed different depths of hardening. It was assumed that this was connected with different oxygen contents in the steels. It is a great pity that the chemical analyses of the steels investigated in these researches are not complete with respect to the determination of gases in the steels. In my opinion, the reasonable prediction of the behaviour of steel during heat-treatment should really be based on the chemical analysis, when such complete analysis can easily be obtained, and on the nature of the atomic arrangement in quenched steels.

Mr. R. J. Brown: I should like to make what may be regarded as some critical comments on the Symposium. Details are given in the Symposium of the standard so-called Jominy test-bar. The American standard Jominy test-bar is produced from a wrought bar, either rolled or forged, whereas in this report only the diameter of the bar is stated, without reference to the material from which the bar is produced, so that a very big variable is at once introduced into all the work which is undertaken.

Another point is that the Jominy test was evolved, I believe, from the user angle, while the papers presented to-day have been presented from the manufacturer's angle. I have no wish to be acrimonious, but as a user I feel that greater control of this property of hardenability, however it may be determined, is essential. In the United States, the tendency before the war was to restrict the chemical composition limits much more closely than in the British specifications, but the adoption of the hardenability test must indicate that even closer limits of composition were not sufficient to "iron out" the differences experienced in the bulk heat-treatment of steel components. I refer to bulk heat-treatment as we do not know it in this country.

I feel that some form of hardenability test, whether the Jominy or any other, is essential. The practical heat-treater is probably more interested in the response of the surface layers of the steel than of the core, but the core has obviously to be taken into account, particularly in the case of a component of varying section machined from a fairly large piece of steel.

Dr. J. H. Whiteley: There is one other point which I should like to mention, and which arises on the paper by Messrs. Pumphrey and Jones. They put forward the interesting suggestion that the hardenability depends on the size of the carbide particles at 850° C., or whatever temperature it is at which they quench.

I think that the authors should have given us more particulars of the steels they investigated, and the particle sizes in them, to satisfy me at any rate that their theory is the right one. I think that the matter might be tested with a plain carbon steel, not a chromium steel. At, say, 800° C. some of the hyper-eutectoid plain carbon steels should show the same sort of differences, if the particle size of the carbide particles enters into the picture.

Dr. W. Steven (in reply): Mr. Service suggested that we should investigate the quality of some of the steels that we tested. The best answer to that is that there are numerous examples in the Symposium of steels which are shown in terms of mechanical tests adequately to meet all normal specifications, and yet are shown to possess wide internal variations of hardenability. He also suggests that some of these variations of hardenability may be due to variations of rolling temperature. The bulk of the end-quench curves in the Symposium were determined on samples which had been normalised before end-quenching, and that should eliminate, partly at any rate, the effect of rolling. A 2-in. or a 3-in. bar is the maximum size on which you can attempt predictions from an end-quenched test specimen, and for air hardening it is not even as great as that.

I was very pleased to hear of the extension of the work by Mr. Bucknall.

We are certainly fully aware of the importance of S-curves in relation to hardenability. I agree that there is very little in the Symposium on that aspect of the matter, but in the near future we shall pay much more attention to the relationship.

With regard to Mr. Burton's remarks, I fully agree that "surface hardenability" is not an ideal term, but I could not think of a better one. It may be that surface hardenability is associated with the columnar structure, but the Sub-Committee at the moment are not prepared to decide on that. In many of the steels we determined copper, tin, arsenic and antimony, but we did not get down to oxygen.

In reply to Mr. Brown, quite deliberately we quote in the test specification only the dimensions of the test specimen. We do not specify that it should be from a wrought bar, because it may be desired to test a casting, in which case it would be futile to use a wrought bar. On the other hand, if you are interested in 2-in. diameter bars and want some indication of the hardness at the mid-radius position of a 2-in. bar, then the experience of the Sub-Committee has indicated that you will get more reliable results by cutting a test specimen from that position.

Mr. Brown suggests that we are well aware of these variations of hardenability within a bar. In retrospect, probably we should have expected those variations of hardenability. On the other hand, I doubt whether anyone would have expected that the hardenability at the centre of a bar would be lower than the hardenability near the surface. His remarks on bulk heat-treatment were interesting, but I think that it is a dangerous generalisation to say that the surface layers are always the more important from the point of view of mechanical tests.

Discussion on "The Influence of Chemical Composition on Hardenability"

Mr. J. Glen introduced the discussion and summarised the information given in the relevant sections of the report.

Mr. J. Woolman: The paper by Mr. Glen emphasises to a very marked degree the difficulty of assessing adequately the hardenability from the composition, even taking into account the influence of grain size, the effect of which, as pointed out by the author, is itself an unknown quantity, since it undoubtedly is also affected by composition.

Apart from the mutual interaction effect of the different elements, there are several other factors which influence the hardenability, and which are not taken care of by the nominal composition and grain size. These are, first, the pre-condition of the steel, as shown by Pumphrey and Jones, as far as it affects the nature and condition of the carbides, and hence the extent and possibly the uniformity of solution of the carbides in the austenite at the hardening temperature; secondly, the presence of residual elements, not usually analysed for, which may have a marked effect, and here I include the gaseous elements, oxygen and nitrogen, which have already been referred to; and thirdly, the mode of crystallisation in the ingot.

I think that the mode of crystallisation really merits further investigation, since it is possibly a very large factor in the failure adequately to predict the centre hardness of quenched specimens from the Jominy test results. It must be borne in mind that hardenabilities are usually measured in terms of the ideal critical diameter obtained by the use of one of several different assumptions from the Jominy test results, such as the log. distance scale or linear distance scale on a Jominy-test-bar, or from half hardness values or from half martensite structure, and these different methods of assessing the ideal critical diameter cannot all represent the conditions at the centre of the bar identically.

The results which Mr. Glen gives go a long way towards elucidating the influence of composition, but there are one or two points to be mentioned in connection with his experiments. First of all, they were carried out on synthetic high-frequency melts, and may therefore not give identical results to those with similar steels made in the electric arc or Siemens furnace. Again, all the steels were first air-cooled from 900° C. and all were given a standard austenitic temperature of 880° C. The air-cooling from 900° C. will have different effects on the state of the carbon in different steels according to their alloy content, and it is possible that some of the complexity of the author's resulting curves showing the effect of composition may be due to this cause. The temperature of 880° C. is rather high for a quenching temperature for many of the steels, so that again the results may not be applicable to ordinary materials hardened from the usual hardening temperature.

Dr. N. P. Allen said that many of the difficulties in assessing the effect of an alloying element upon hardenability arise from the fact that there is no such property of a steel as hardenability at all. The effect of an alloying element on hardenability is really a complex resultant of the effect of the alloying element on all those reactions which may take place between the quenching temperature and the temperature at which martensite forms, and the effect of the alloying element upon the hardness of such reaction products as appear if the cooling is sufficiently slow.

It really is not to be expected that the effect of an alloying element shall be expressible in a single figure such as Grossmann's multiplying factor, and it is not surprising that Mr. Glen finds it is very difficult to discover what such a multiplying factor is. The fact of the matter is that it is impossible. It is to be expected that it would be impossible, and I think that Mr. Grossmann has a good deal to answer for in setting us out on this false track, because when he started his work there was sufficient information on the subject to enable him to know that this mode of attack would not work. This multiplying factor is essentially a wrong idea, and what we have to do is to retrace our steps and patiently pick the problem into its various parts, studying the effect of the alloying elements on each of the reactions which are important in this connection. That will take us a very long time.

Mr. H. Allsop: Mr. Woolman referred to the possible effect of ingot structure on hardenability. We have done some preliminary work since the matter was submitted for this Symposium, and there does appear to be a connection between the macrostructure in the billets and the limits of the zone of low hardenability in the centre; but, to hark back to what Mr. Burton said earlier, the limits of the low hardenability zone do not appear to coincide with the limits of the columnar zone, and for one or two reasons it would appear that that columnar zone is not the high hardenability zone, or what Dr. Steven and I call the surface material.

Mr. E. H. Bucknall: In our laboratories, parallel determinations of isothermal transformation characteristics and Jominy curves have convinced us that the isothermal transformation characteristics can be regarded as a hardenability measurement, a more precise and discerning hardenability measurement, and one which expands the range of testing far beyond that with which the Jominy test can cope. I wasted a good deal of time trying to systematise on a calculation basis the effect of alloying elements as they contribute to transformation characteristics. When we were expressing the effect of elements on transformation by means of the transformation velocity, which is the velocity of a first order reaction corresponding to the fastest transformation shown in the steel, dealing with single additions there did seem often to be a simple rule that each progressive addition of, let us say, 0·1% reduced the transformation velocity by a constant factor. That factor was approximately 0·4 for carbon, 0·76 for manganese, and so on. But efforts to calculate the behaviour of complex steels on that basis, even when they are confined to steels which had similar transformation habits, when they were confined to the intermediate transformation range were quite unsuccessful, even when we went so far as to say: "Let us assume that though the individual elements have different effects according to what other elements are present, their effects will be constant when they are added to a steel which already has a given transformation velocity."

Dr. R. Genders: A point which emerges from this Symposium is that there is an enormous field for further work, and particularly in what I regard as a rather more suitable field for the application of hardenability experimentation, and that is in the field of steels which are used in the near-completely-hard (rather a bad term !) condition, and especially in the tool steel field. I feel certain that in that field we shall obtain very valuable progress indeed, far more so than in this present field of engineering steels, which are, after all, pretty well tempered and have their gradient of properties very much flattened out by the treatment subsequent to hardening. We ought to be very grateful for the early work of Jominy, which was a brilliant attempt to obtain in a simple manner results such as we had been obtaining by a very much more lengthy type of experimental work in the past.

Mr. J. Glen (in reply): Mr. Woolman raised one or two points regarding the type of steel which we used in these experiments. We used high-frequency casts made in a small, 18-lb. furnace because there is very little variation in hardenability with such a steel.

With regard to the heat-treatment of the samples, we gave the steels a 920° C. treatment first of all to standardise them. I think that the Committee agreed with that type of treatment, and we found that by doing the Jominy test at 880° C. we could get a fairly good, uniform austenitic grain size in all the steels.

Dr. Allen says that there is no such thing as hardenability or multiplying factors, and in some ways I agree with him, because we found it difficult to obtain the multiplying factors; but I agree very much with what Dr. Genders said, that a new method of approach should be explored very fully.

In reply to Mr. Bucknall, I made it clear in the paper why we chose the point of inflection in the Jominy test; indeed, the difficulty was such that we had no alternative, and I should like him to suggest a better criterion than that which we tried to adopt. In these small high-frequency casts we found that the addition of boron and aluminium or aluminium alone, gave very uniform results, with the exception of very simple steels containing less than 0·4% carbon. In the alloy steels we found it more easy to get uniform Jominy tests; it was only in a few steels of the simple type that we found any marked irregularities in the Jominy test.

The Prediction of Hardness and Transformation Ranges from End-quench Hardenability Curves

Mr. T. F. Russell introduced the discussion on this group, and summarised the information given in the relevant sections of the report.

Dr. N. P. Allen: I propose to devote my remarks to the first proposition, which is that this correlation which has been worked out is on the right lines and that, provided we take the variations of hardenability across the section

into account, we can predict the hardness which will exist in a quenched bar.

I propose to act somewhat in the way of "devil's advocate" here, and to see to what extent this conclusion can be shot at. It is necessary to examine the assumptions behind those calculations. We have to assume that if in two pieces of the same kind of steel the cooling rates are the same at two points, the hardness and general properties will be the same; and then we determine experimentally the rate of cooling along a Jominy bar of the steel and calculate the rate of cooling at a point inside another quenched bar of the same steel in which we are interested, and the whole problem is to calculate the rate of cooling inside an unknown bar—inside any particular bar of an unknown steel.

Those calculations are complicated, and they involve a knowledge of three things: the rate of heat transfer across the surface of the steel, the specific heat of the steel at every point (and with the specific heat we have to include any latent heat which is given out), and the thermal conductivity of the steel at every point; but those characteristics of the material vary from point to point through the steel, and they vary from time to time during the quench.

With regard to the second point, the validity of the half-temperature time as a criterion of cooling rate, we are in a much happier position, because here we know quite definitely that we are wrong. The paper by Jones and Pumphrey, which Mr. Russell was inclined to pass over, shows that the majority of the steels of the types in which we are interested transform at temperatures below the half-temperature point; and studies of isothermal transformations on various alloy steels would indicate that this is the general state of affairs. This correlation, therefore, ought to be based on a rate of cooling decided at a somewhat lower temperature, more in the region, for the average steel, of 500°–300° C. than in the region of 900°–700° C. or 900°–550° C., as it is at the moment.

From a theoretical point of view, therefore, there are quite a number of objections to this mode of correlation which has been worked out, and in view of all those objections it is surprising that the correlation is as good as in fact it is.

I do not wish to be understood to minimise the importance of the Jominy test or its usefulness, but I do feel that there is a case against over-elaboration of the mathematical side of the problem: I feel that the virtue of the Jominy test is really in its simplicity, and a rather good comparison can be made between the Jominy test and the Brinell hardness test. We shall use it, and use such rough correlations as appear suitable by rule of thumb methods, and get on a great deal faster that way, and we shall be on sounder ground than if we attempt to calculate too far beyond the limits of our exact knowledge of the material.

Mr. E. H. Bucknall: When people are trying to interpret Jominy results beyond the safe point, they will find a good deal of encouragement in the use of Mr. Russell's nomograph, which I am sure will give them the sensation that they are being highly academic, but will leave them with the difficulty that they will have to decide for themselves on an approximate value of H for quenching conditions when the correlation is being made from a Jominy test to a result on a quenched bar for which prediction is needed.

Mr. T. F. Russell (in reply): First of all, I should like to make it clear on behalf of the Sub-Committee that they lay no claim at all to originality in this half-temperature time as being a criterion of cooling rate. We simply investigated what the Americans emphasised most; the Americans are very keen on the half-temperature time, and that is why we examined it instead of trying to find any other criterion which would be better. Personally, I do not think that we shall find any better criterion than the half-temperature time.

Dr. Allen says that such things as the specific heat, the thermal conductivity, the specific density and so on all vary with temperature. Actually we are not interested in any of them; we are interested in the combination of the three, called thermal diffusivity, which is the thermal conductivity over the specific volume. I do not know, but is not it possible that some of these may vary in different directions, so that we do get a constant?

Mr. Bucknall's contribution to the discussion was very interesting. The only point with which I need deal now is what is the cause of this scatter in H which we are finding. I think I am right in saying that if the Sub-Committee were to start all over again we should naturally benefit by our mistakes. Some of the bars would not be quenched by hand, and the personal element would be wiped out completely. The Jominy test is, after all, a commercial test, and we should benefit by our mistakes, but I am convinced that most of the variation in H which the Sub-Committee have found is due primarily to differences in the steels.

The Influence of Hardenability on Mechanical Properties

Mr. W. E. Bardgett introduced the discussion on this group, and summarised the relevant sections of the report.

Mr. H. Bull: The Jominy hardenability test, to be of any practical value in a steelworks, must afford a quick and ready means of assessing the properties of a cast of steel. I do not think that the work in this section of the report shows that the Jominy hardenability test fails so much as a hardenability test, but it does fail to measure some of the properties which we call mechanical properties, and in particular it fails to give us any measure of the toughness of a cast.

If we accept Conclusion 3 we are left in just the position that we were in before, in that if we want to know what the mechanical properties are going to be on any size of bar from any cast we must take that size of bar and put it through a heat-treatment and make a test, and the Jominy test does not help us. That may be because we in this country lay great emphasis on the need for tough steels.

There is no doubt, I think, that the steelmaking industry in particular would welcome any ready means of assessing the properties of steel, and assessing them quickly, so that the work of the Sub-Committee in providing a substitute for the Jominy test would be very welcome. It is most desirable that such a test should be capable of application in much the way that a sample passer or shop chemist applies his knowledge when the steel is in the furnace.

It is not clear to me sometimes whether the test-pieces, after tempering, were cooled in air or in water, and I wondered whether temper brittleness had crept in to some of the casts, because freedom from temper brittleness cannot be assured altogether by putting molybdenum into the steel, and it may be that some of the casts were more temper-brittle than others. I do not know whether it is within the province of the Hardenability Sub-Committee to deal with that question, but it is one of the things about which we have no explanation. I am still talking about impacts and alloy steels. I do not know whether there is any relationship between these things. We are aware of a trough in the impact curves when the steels are tempered round about 300°–400° C. I think that the toughest steels have the least semblance of a trough. If we can persuade the Hardenability Sub-Committee to pursue their work and tell us a good deal more about the things which must grow out of their present work, it would add to our knowledge of such matters as I have mentioned.

Mr. F. E. Stokeld: As one working in the drop-forging industry, I should like to say that we are particularly interested in the relationship between what we, like many other people, call hardenability and mechanical properties. We deal with a very large variety of heat-treatable steels, all of which when in the form of forgings must give the specified mechanical properties before they are delivered and afterwards.

With some steels our difficulties are few and far between, but with others they are much greater. My own experience

points to two common steels as being the most serious offenders, and in both cases the difficulties seem to be due to lack of hardenability. This phenomenon is the more troublesome to drop forgers because we have to try to avoid the use of water quenching. Because of the necessity to use oil quenching wherever possible, we cannot afford to make forgings from steels possessing abnormally low hardenability characteristics. We had one consignment of steel which for some reason was not tested first in this way, and the forgings had a ruling section of about 1 in. and contained pads about $\frac{3}{8}$ in. thick. They were produced from this steel, and when water-quenched from 850° C. and even higher temperatures they gave only 460–520 VPN, whereas usually we get about 700 VPN at least. That steel was submitted to the Jominy test and compared with another more normal steel, and we got very similar curves; the Jominy test did not differentiate between them. The McQuaid-Ehn grain size for these steels was much the same, about 6–7, and we considered that this would have little influence on the variety of the results.

Another troublesome variety to us was the carbon-manganese-molybdenum steel usually known as En 16. Here the trouble was not surface hardness only, but particularly difficulties due to the depth of hardness produced by heat-treatment. We made some investigations and found that it was necessary to obtain Brinell hardness numbers of at least 269 on the surface of test samples and forgings to ensure an ultimate stress of over 55 tons/sq. in. on axial test pieces. In many instances, unfortunately, it became necessary to resort to water quenching when hardening some of the forgings, and, despite every care, a number of them were cracked and therefore scrapped. We then resorted to another type of test, and this has given more satisfaction. It is along the lines mentioned by Mr. Bull. We resorted to the hardening and tempering of samples from each delivery of bars and billets. After forging samples to the largest ruling section of the forgings, we intended making from each size and cast, we hardened in oil and tempered at a standard temperature of 540° C. We then cut through the sample and obtained Brinell hardness numbers on the surface and on the axis of the section. We also made a nicked fracture. From the results of these tests we were able to judge the suitability of the material for the purpose intended.

We have been warned that caution is needed when the end-quench test is considered as a possible specification requirement. I support this very fully, because I fail to see any advantage in its use in the field of standard specifications. I feel, however, that much publicity should be given to the finding that a cast of steel cannot be adequately represented by a single end-quench test, and also to the finding that full hardening is necessary to secure optimum mechanical properties. These are important points which need to be kept in mind when future work is undertaken for the improvement of steel quality.

Mr. E. H. Bucknall: As a warning against anyone wanting to take the interpretation of the Jominy test as regards mechanical properties any further, I feel that reference should be made to Section IVc of the Report, where in a paper to which little attention has been given to-day Pumphrey and Jones have described their study of the transformation ranges of hypereutectoid steels by means of interrupted Jominy end-quenches. It is, I think, impossible to exaggerate the value of such work in the field between the Jominy test and transformation measurements as regards finding out the fundamentals of the mechanical properties of alloy steels. The Jominy curve as normally determined tells one almost nothing from that point of view. When one looks at it, one may infer the cooling rates which cause particular degrees of transformation corresponding to the hardness falls in the Jominy curve, but one gets nothing from an examination of the ordinary Jominy curve itself.

Referring to work being carried out in the Mond Nickel Laboratory, he thought it could be said quite definitely that little support is given to the contention which used to be advanced in America that so long as the same microstructure is achieved in quenching, the mechanical properties of steels are the same. That assertion is fortunately being watered down to-day. Dr. Swinden in his preface drew attention to a statement by Gillett which took a lot away from that point of view and I think it will be a good thing when it disappears completely. It is one of those things which, if it were ever true, were based on a happy chance. For that reason, I think that it falls into the same class as the American experience in the early days of the work of Jominy and Grossmann, that their steels always gave a smooth U-curve representing the hardness traverse across a section, which was a very fortunate circumstance indeed, since none of our steels have ever shown anything remotely resembling that U-curve.

Lieut.-Col. T. B. Bierniacki: It seems to me that we expect too much in attempting to predict the mechanical properties of a given steel of given section from the Jominy hardenability test. This test is obviously limited to only one property—namely, the hardness of a given steel. No relationship has yet been well-established between the mechanical properties and the hardness, unless it is a very approximate one between the tensile strength and the hardness. I am not surprised, therefore, that in this work the attempt to establish a relationship between the results of Jominy tests and the mechanical properties was not successful.

In my opinion, the value of the Jominy test is that we can say by a very simple method what hardness we expect to obtain in a given section of a round bar, and we can say that this is some indication from which we can judge what we ought to give as heat-treatment for a given steel.

Mr. J. D. Hannah: There is one field in which I think the Jominy test does fit completely, but it has not been dealt with by the Sub-Committee, possibly because it is not seriously concerned in the question of the conservation of alloys. It relates to steels which are used for the production of tools, and in particular of tools used for the production by pressing operations of small parts used in light engineering. There are innumerable kinds of parts of that description, but the production of certain small arm munition components—cartridges, bullet envelopes and so on—may perhaps be taken as typical.

These tools are used completely untempered, and the sequence of hardening presents an exact anology to that which obtains in the Jominy test-piece. Obtaining steels for the purpose of making dies of this sort from perhaps half a dozen steelmakers, all making it to the same nominal analysis, and keeping very closely to the same nominal analysis, presented a situation in which the hardenability, represented by the depth of hardening on the particular tool, varied from perhaps 0·03 or 0·04 in. up to as much as $\frac{3}{8}$ in. The result, of course, was chaos, and it remains chaotic. All that we could do was to adopt a test by making a simple drill hole through a block and trying the ones which fell within limits which experience showed to be suitable for the particular job. It seems to me that the Jominy test would be directly applicable to the exploration of whatever may be the ultimate explanation of such remarkable differences in hardenability as obtained with steels of that class.

Mr. A. Preece: I should like to ask one simple question, and that is whether the Sub-Committee have considered the diffusion rates of carbon and other elements in the steels which they are studying. Fundamentally, hardenability is really a problem in diffusion, and it occurs to me that any information which could be obtained in research of that type might be of some use in the solution of the main problem.

Mr. W. E. Bardgett (in reply): Mr. Bull made a number of very interesting comments, with which it is

difficult to deal in detail. The process of devising a special test for a particular purpose is one with which most of us are acquainted, and something useful is more likely to arise from it than from a test which is intended to have a wide application. On the question of temper brittleness, in most cases the steels have been either of the type which are free from temper brittleness or actually oil-quenched from the tempering temperature.

Mr. Stokeld's remarks were very interesting. The development of the technique of testing for a particular product can be made to give a fairly reliable measure of its ability to satisfy the particular requirements. The Hardenability Sub-Committee greatly appreciate suggestions made for future work, which will be borne closely in mind.

Mr. Bucknall's remarks do not call for any particular comment. They add very appreciably to the information made available to-day, and we shall particularly welcome information on the further work which he is carrying out, if it can be made available.

Reference has been made to the fact that we should not expect too much from the Jominy test. It may appear that we have been doing so, but it is, of course, necessary to explore its complete possibilities. Whilst it does only measure hardness, we know that hardness bears some relation to mechanical properties, and therefore the natural outcome was to investigate just how far the method could be applied in assessing mechanical properties.

The application of the Jominy test to the particular case mentioned of a die is, I think, probably direct; the hardenability as measured by the Jominy test gives you precisely what you want to know in a particular die. There are other examples, such as cold rolls, where you want as high a hardness as possible and a certain gradation of hardness and a certain depth of hardness, as the material is only lightly tempered, and therefore the Jominy test should give you a very good measure of the behaviour of the particular material which you are going to use for the rolls. There again, of course, the question of casting characteristics comes in, and in the high tensile condition you may still get differences in different casts which may give rise to trouble due to different degrees of toughness, and of course, in these materials, and particularly rolls, a certain degree of toughness is required.

With regard to the measurement of diffusion and its bearing on hardenability, there is no question at all that that is a very important field in this connection, and it is one which the Sub-Committee must and will bear in mind when considering future work.

Mr. D. A. Oliver: You will appreciate that it is not possible to deal in a wholly adequate way with all the points which have been raised. First of all, I think we must confess as a Sub-Committee that we are wiser after the experience than before, and, as Mr. Russell emphasised, there are certain parts of the work which would have been done a little quicker or a little more elegantly had we had all our experience at the beginning of the job. In point of fact, we had very little experience at that time, and that is our excuse for going slowly and attempting to examine all the claims made for the test, even those which for *a priori* reasons might be expected to be rather excessive.

I should, however, like to emphasise that quite apart from this question of the Jominy test there is in this Symposium a mass of very careful experimental work on British En steels which can be looked on as almost an encyclopædia of heat-treatment. Whether the calculated curves fit the measured curves or not does not detract from the value of the measurements, and I think that that is a point which is worthy of emphasis.

Furthermore, I have to announce that the Sub-Committee's life is coming to an end. Its parent Committee has already passed out with honour, and the Sub-Committee is due to follow it at a not distant date. We are, however, glad that the British Iron and Steel Research Association, through its Thermal Sub-Committee *A*, is probably going to absorb a large proportion of the membership, and that hardenability in future will be studied side by side with isothermal and other forms of transformation. I submit that that is a complete answer to the large number of speakers who have emphasised the enormous importance of studying hardenability alongside isothermal work, and, as Mr. Preece has rightly emphasised, the diffusion of elements and alloys.

The possibility of finding newer tests will be carefully noted. You will gather from the size of the Report that we had our work cut out in sticking faithfully to one test. As the work which you have before you was finished in 1945, and as the members, having become interested in the subject, have continued it, as you have heard, to a far greater degree in certain directions, possibly the time has now come when new tests can very intelligently be examined. The point which Dr. Genders raised this morning as to the value of end-quench testing of tool steels is much too good a point to miss.

It may be that this work will find its greatest value in the future in the tool steel field. For any component which has to be put into use in a condition approximating almost to the as-quenched condition—i.e., the quenched and very lightly tempered condition—a great deal of information can be secured from Jominy tests. Besides tool steels, we have had the example just quoted by Mr. Bardgett of rolls, and another application which comes to mind is that of lightly tempered springs. It may be that in these fields, which were outside the scope of our original terms of reference, there will be a harvest in the future.

We also seem to have discovered a very sensitive test of heterogeneity, and consequently to those interested in exploring ingot structure and distribution the test may have value in that regard.

In conclusion, on behalf of the Sub-Committee I should like to thank all those who have obviously spent a great deal of time in studying the Report and who have clearly taken an interest in it for their suggestions as to weak spots and as to where new work could usefully be carried out. I should like to say how much the Sub-Committee has appreciated the reception given to this Symposium.

Gas Malleableising

In our reference to gas malleableising on page 38 of our May issue, we omitted to mention that the process developed by Birlec, Ltd. is fully patented by that Company. As mentioned, the furnace illustrated on the page referred to is 14 ft. × 5 ft. × 2 ft. high: it is designed for annealing malleable conduit fittings and similar light parts, and it will accommodate loads of 4–5 tons. The operating temperature is about 1,050° C., and the total cycle time is between 24 and 40 hours, according to the thickness of castings.

Bristol Aeroplane Company's New Interest

A new Company has been formed, with the title of British Messier, Ltd., to develop and market aeroplane undercarriage, hydraulic, pneumatic and electrical equipment, based upon the well-known French Messier designs of the Societe Messier, Paris.

The directors of the new Company, in which the Bristol Aeroplane Co., Ltd. is taking an interest, are Mr. W. R. Verdon Smith, Head Office Director of the B.A.C., Mr. L. S. Armandias (Managing Director), Air Commodore F. R. Banks, C.B., O.B.E., and Mr. H. G. Conway (Technical Director). The Secretary is Mr. W. Masterton, who is also Secretary of the B.A.C.

British Messier, Ltd., has its own technical and design staff and development facilities, and will have the benefit of manufacturing facilities by arrangement with Rotol, Ltd.

Development of an Oil-fired Pile-heating Furnace for the Wrought Iron Industry

By L. G. A. Leonard

The attainment of high thermal efficiency in pile-heating furnaces is affected by many factors in the manufacturing methods which cause extravagance in the use of heat. Coal is generally used to heat these furnaces but the need to conserve this fuel has directed attention to the use of oil fuel for the purpose, and a furnace is described which has been specially designed for pile heating which is fired by oil-fuel. In operation it has a thermal efficiency about treble that of the coal-fired furnace it replaced.

ONE of the oldest established industries in this country is that engaged in the manufacture of wrought iron, but there have been few changes in the process during the last 100 years. Compared with steel making, methods of manufacture are extravagant in heat and so have a material bearing on the cost of the finished product. One reason is that the temperatures used are very high, and there are factors involved which do not permit economic loading of the furnaces. For instance, in a typical pile-heating furnace the material in the shape of bars cannot be continuously heated as in a pusher-type furnace such as used in the steel industry due to the high temperature and the presence of molten slag or cinder, which would cause the piles to weld together. Each pile, therefore, must be individually charged and must not come into contact with other material.

Another difficulty which militates against the attainment of high thermal efficiency is the considerable loss which takes place by formation of slag, or what is commonly termed in the trade "cinder." This is an appreciable proportion of output and it is obvious that anything done to reduce this loss will improve the fuel position by ensuring a greater output of wrought iron for a given quantity of fuel used.

Another factor bearing on fuel cost is the exceedingly corrosive action of the slag or cinder on normal refractories. Furnaces must be shut down at frequent intervals for repairs and renewals, resulting in a considerable waste of heat. There is a great need for the development of furnaces which will give increased thermal efficiency with a longer working life and reduction in the amount of slag produced.

These features have all been given consideration by the wrought iron industry. Early in 1946 Messrs. Thos. Walmsley & Sons, Ltd., Bolton, came to the conclusion there would not be sufficient coal available during 1947, which made it imperative to consider other fuels which could replace coal, and at the same time enable some of the problems outlined to be overcome. After consultation with the Dowson & Mason Gas Plant Co. Ltd. and the Petroleum Board it was decided to instal an experimental pile-heating furnace heated with liquid fuel instead of coal. At the same time it was decided to build certain portions of this furnace with special refractories, and Messrs. General Refractories, Ltd. were approached. The pile-heating furnace is only one of the types used in the industry, but it was thought if a successful oil-fired unit could be developed the experience gained would be valuable in tackling the problems encountered in the puddling and scrap reheating furnaces.

Pile-heating furnaces use bars produced by the scrap reheating and puddling processes, these bars being

Fig. 1.—A recently developed dual batch-type furnace, fired by oil fuel, used in the manufacture of wrought iron.

Fig. 2.—Drawing a pile from an oil-fired furnace preparatory to rolling into a wrought iron bar.

about 18 in. to 3 ft. long and 3 to 6 in. in width, five or six, or more, being placed on top of one another and heated in the furnace so they become welded together, after which the welded billet is rolled again into bars. This process assists in giving wrought iron its typical fibrous structure.

After each heat it is necessary to cover the bottom of the furnace with a layer of silica sand which is fritted to form a new bottom. The necessity of remaking the hearth after each heat is another factor which mitigates against the attainment of high thermal efficiency.

The furnace developed by Messrs. Thos. Walmsley & Sons, Ltd., and the Dowson & Mason Gas Plant Co. Ltd. is of the dual-batch type having two chambers used alternately for preheating and heating. The preheating chamber is valuable in reducing the amount of fuel required for heating the wrought iron, but it also saves considerable time, since the sand can be fritted to the hearth of one chamber while billets are in the other. Each chamber is heated by two low pressure oil burners firing under a reverberatory arch, the waste gases passing from one chamber to the other, under a section of the arch which is brought down as close as possible to the hearth. Owing to the corrosive nature of the slag it is not possible to have a wall between the two chambers, and therefore, the arch itself is brought near to the hearth to form a restriction. Doors are arranged in the back and front walls of each chamber which allow the piles to be charged and discharged with a minimum of effort. In the older coal-fired furnaces the doors are usually arranged on one side which results in extra labour for the furnace men charging the piles placed near to the back wall.

The new furnace is designed for an output of about 25 tons per shift of 9½ hours, and each chamber has an effective hearth of 7 ft. × 8 ft. 6 in. wide. The piles in the heating section are brought to a temperature of 1,475° C. in 35 mins. or less, after previously being preheated to 1,100° C. in the other chamber. The whole of the piles in the heating chamber are withdrawn in 30–60 mins. according to size, after which it is necessary to remake the furnace bottom before recharging with cold material. At this time the chambers are reversed, one lever being operated to change over the air and oil supplies, while another lever is moved to reverse the flow of gases through the furnace.

Due to the high operating temperature it is necessary to protect the oil burners not in use from the hot gases and radiation from the walls of the furnace. For this reason heat-resisting iron sealing plates are automatically dropped over the oil burner openings when the burners are shut off. This prevents any oil that may have been left within the burner bodies from carbonising and the plates also prevent leakage of cold air into the furnace. The burners use air at a pressure of 16 in. w.g. with fuel oil preheated to a temperature of 180° F. by thermostatically controlled tubular steam heaters.

Many of the coal-fired furnaces used for this process are bricked solid from the ground up to hearth level, and as the slag percolates this brickwork there is a tendency for it to expand until the buckstays and the casing of the furnace are forced outwards. When this particular furnace was designed it was decided to introduce an air-cooled bottom to obviate this trouble. A large mild steel box divided into a number of sections was incorporated so that the air on its way to the burners was given a circuitous path under the base of the furnace. This cools the hearth and at the same time preheats the air for combustion which helps to reduce fuel consumption.

The refractories consisted of sillimanite, chrome magnesite, spinella, first quality Glenboig firebricks as well as high temperature insulating refractory bricks. The sillimanite and Glenboig bricks formed the crown of the furnace and there is every indication that their use will give a much longer life than is obtained in the normal coal-fired pile-heating furnace. The insulating bricks were used as a backing to the other refractories in the construction of the side walls, and it is noticeable that the temperature of the outside of the walls is very much lower than in the coal-fired furnace with consequent improvement in the working conditions for operators. The chrome magnesite and spinella bricks have not been so successful as the other refractories, although experiments are still being made to develop new refractory mixtures which will withstand the very corrosive slag.

The fuel consumption is much lower than was first thought possible and the thermal efficiency is about treble that of the coal-fired furnace replaced. The furnace is now being altered to increase the area of hearth allowing a greater weight of material to be charged which will result in a larger output, and at the same time still further increase the thermal efficiency.

The Preservation of Metallurgical Microspecimens

By Henry Thompson, A.R.Ae.S.

It is frequently desirable to retain a polished microspecimen for some period after its final polish, either because of the necessity for further examination, or the specimen may reveal a structure which would be lost if it were to be subjected to repolishing. Several methods are used to preserve such a surface, the commonest being the use of grease or a film of oil applied to the surface. A recent method is used whereby a small piece of Aroclor 4465 (one of the chlorinated diphenyl resins) is melted on the surface of the specimen and this is covered with a microscope cover glass disc, thereby forming a transparent layer of melted resin between specimen and the glass.

The thermoplastic lucite has also been used; the method depending upon the positioning of the specimen in the mould, which ensures a film of transparent lucite over the surface of the specimen.

A simple method used by the writer consists of applying to the surface of the specimen, a coating of the following solution :—

Distrene	15 gms.
Polymethylene	10 mls.
Benzene	100 mls.

The solution dries very quickly and forms a flexible film which can be stripped off when desired by lifting one edge of the film and peeling off the remainder. The use of this solution is not confined to microspecimens, as it has been used in the preservation of etched and polished surfaces of steel billet sections and for the preservation of materials which reveal cracks, flaws and discontinuities which it is desirable to retain for further examination.

PROGRESS IN CASTING

A Review of American Foundry Practice

Wartime progress in casting in the United States has been discussed by six foundry experts of the Battelle Memorial Institute. In the present summary, the papers by the various authors, dealing with developments in grey iron, malleable iron, steel, brass and bronze, aluminium, and magnesium castings, are briefly reviewed.*

THE importance of grey cast iron as a versatile and valuable material suitable for new applications, was realised more fully by engineers and designers as a result of wartime experience. This is pointed out by T. Barlow, who deals with wartime progress in such castings resulting in an increase in mechanisation, greater operating control and improvements in research developments, all of which tended to increase the qualities of the products.

Mechanisation of grey iron foundries was a major development and was brought about largely from attempts to meet the unusual demands for castings resulting from manpower shortage and obsolete and poorly adapted equipment. This mechanisation started in many cases at the melting unit, with changes to mechanical charging, rapid methods of weighing and the handling of raw materials, followed by an increased melting capacity, better control equipment, and mechanised molten-metal-handling equipment. The increased melting capacity of the foundry was kept pace with by automatic moulding, conveyor lines, increased cleaning facilities, overhead handling equipment, etc.

Few changes were made in the basic method of producing cast iron although there were minor improvements in almost every phase of the work. The cupola remained supreme in the melting field, but improvements were made in many cases: (1) By the adoption of cupola air furnace duplex units; (2) an increase in the number of hot-blast cupolas; (3) an increase in the number of balanced-blast cupolas and (4) a large increase in control equipment such as blast control, temperature control and humidity control.

To meet exacting specification, foundrymen gave greater attention to the control of the many variables occurring in foundry practice and more attention was given to chill tests, moisture control, melting control, sand control, scientific moulding and gating, chemical analysis and physical testing. The inoculation process was also used to a greater extent to obtain more reproducible properties in cast iron. Resulting from these various improvements, the upper limit of tensile strength of grey cast iron was extended to 45–50 tons/sq. in. Crankshafts, high-pressure castings, high-strength valve castings, centrifugally cast liners, high-strength piston rings and composite-metal castings were some of the applications of cast iron developed.

The modernisation of foundries which was stimulated by war needs and which included the more general adoption of continuous melting, the use of mould conveyors and mechanical sand-handling equipment, and the installation of more efficient types of annealing ovens are considered by C. H. Lorig as showing progress in the malleable iron industry. New foundries were built incorporating improved operating practices, machinery and equipment, and many established foundries were modernised to permit substantially higher output in the same floor space and with the same or less labour. Two new plants built during the war provided many interesting features with special emphasis on improvement of working conditions.

In line with modern plant layout, continuous-pouring units were designed to use cupola-electric furnace duplexing in one plant and cupola-air furnace duplexing in the other. In one plant also, annealing was carried out in elevator car-type electric annealing furnaces, and in the other in portable batch-type, radiant-tube, gas-fired ovens with atmospheric control. With this new type of furnace equipment the total time of annealing was reduced to 72 hours. The trend towards continuous melting and duplexing was rapidly accelerated and over half the malleable iron tonnage was finally being produced by the continuous method.

In melting practice further aid to production was obtained by installing equipment for controlling the humidity of the blast in the cupola. In moulding practice few changes were made, although some slight progress was made in applying centrifuging methods, and in the use of synthetic sands. Metallurgical developments in the industry were few, being virtually confined to additions of minute quantities of boron, 0·001%–0·003%, and tellurium for better control of annealing practice. Refinement of temper-carbon nodules in malleable iron accompanied the boron treatment and such refinement reduced the time for both stages of annealing. In war applications, malleable iron was used for many parts where strength, toughness, and decidedly superior casting and machining qualities were required.

Progress in steel castings, dealt with by C. E. Sims, was notable for the outstanding development brought about by the substitution of such castings for forgings. Large quantities of steel castings for such a purpose were produced to very exacting specifications. New problems in foundry technique and metallurgy were presented and were only overcome after much work had been done on them. The resulting product proved conclusively that well-made castings could compete with forgings so far as all service requirements were concerned.

Steel-making methods in general were not changed but more attention had to be given to the utilisation of lower grade scrap and to the conservation of alloys. Compositions of cast steel were not altered to any material extent, but new compositions were introduced and a larger proportion of castings was made of alloy and high-strength steels. While no entirely new foundry techniques were developed, there was a decided stimulus

* *The Foundry*, 1946, **74**, No. 1, pp. 70 to 103.

to concentrate on the newest and best methods known, including the atmospheric pressure feeding of castings, the use of special pencil and wafer cores and of graphite rods, and the use of better patterns. More attention was given to sand and sand conditioning and an outstanding advance was made in centrifugal casting. Precision casting also found new fields of usefulness in the application of the lost-wax moulding process.

A most significant change in steel casting progress took place in the heat-treatment of castings and this change affected both methods and equipment. Water quenching of castings took a prominent place and not only were small castings so treated but the water quenching of parts weighing thousands of pounds also became commonplace. Steels were made to specified hardenabilities and it was found there were no important differences between cast and wrought steel in regard to S-curves, hardenabilities, or hardenability calculations. Martempering has also been successfully applied to castings although considerable difficulty was encountered in attempts to use this principle on heavy sections. An important outcome of this trend in heat-treatment has been the acquisition by many foundries of excellent heat-treatment facilities.

In common with other products, steel castings were made to more rigid requirements and this factor demanded more searching methods of testing and inspection. Both X-ray and magnetic powder methods of inspection were widely adapted, and considerable use was made of the Jominy hardenability test.

Among the many products developed as steel castings were tank armour, ordnance castings, centrifugally cast aircraft engine sleeves and gun barrels, and cast rotors and stators for superchargers.

According to A. H. Hesse, the most notable development in brass and bronze foundries during recent years was of a metallurgical nature, in the increased use of manganese bronze. Because of difficulties of producing sound castings and satisfactory physical properties, use of this alloy previously was confined largely to the production of marine propellers, in which its strength and resistance to sea-water corrosion were of prime importance. Intensive research and development of the alloy clarified the understanding of its casting characteristics and composition limits so as to make possible the use of manganese bronze in rings, hollow cylinders and other small parts, particularly those exposed to corrosive atmosphere or salt spray. The use of this alloy also conserved both copper and tin, and another advantage arose from the large potential supplies of fired cartridge case which could readily be converted without deleterious effects on the properties of the alloy. Silicon bronze was another alloy which was limited in application prior to the war, but was used more extensively as a result of wartime necessity for tin conservation. Its low resistance to sea-water corrosion and its high copper content, however, placed limitations on the extent to which the alloy could be employed.

Facilities for producing non-ferrous castings centrifugally were expanded during wartime, the process being readily adaptable for producing hollow cylindrical shapes and other castings of simple design and was used in many cases to supplant forgings or parts made from wrought materials. The centrifugal casting process was widely used for the manufacture of bearings and for certain aircraft parts made of aluminium bronze, in which high strength and high quality of castings were of prime importance. Precision casting methods were also extended to the non-ferrous industry.

During the period, many bronze foundries were modernised and new equipment installed. Lift-coil induction furnaces were acquired to replace oil-type crucible furnaces, and moulding machines were installed and supplied with sand from overhead distributing belts. Cupola melting of bronze also received a good deal of attention and accurate results were obtained from this method of melting. The cupola was found to provide a more rapid and cheaper method of melting bronze than was possible in any other type of furnace.

A substantial expansion of facilities, mechanisation and betterment of production and a general improvement in the quality of castings are considered by L. W. Eastwood to be the most important developments in the casting of aluminium alloys. Progress was also recorded in the further development and application of testing procedures, methods of casting, selection of alloys and expansion in the use of permanent moulds.

Wartime demands expanded the industry's capacity to seven or eight times that of pre-war production. To meet such an increase, aluminium foundries were forced into high-production methods, which necessitated the adoption of mechanisation. General improvement in the quality of castings was accomplished by the careful and studied application of good foundry practices. Degassing operations were invariably employed and the use of boron trichloride as a degassing and grain-refining agent was revived. Wartime development in alloys consisted of the greater use of high-purity, aluminium-copper alloys, the wider use of the high-purity aluminium alloy containing 10% of magnesium, the introduction of the aluminium-zinc-magnesium casting alloys and the very wide use of aluminium-silicon-magnesium alloys for general-purpose high-quality castings.

During the past five years the art of making aluminium permanent-mould castings and their acceptance and use have markedly progressed. The production of permanent-mould and semi-permanent-mould castings expanded enormously, the general quality improved, and castings of greatly increased size and complexity were produced successfully. Die-casting procedure also received considerable impetus during the war, but centrifugal casting is still in the experimental stage. The use of plaster moulds and cores has received considerable attention, the precision casting or lost-wax method has been used successfully, and the use of cement moulding has had considerable application for the production of castings of the higher-melting-point alloys. Improvements have also been made in standard melting equipment and an adaptation of the low-frequency electric brass-melting furnace has been introduced for aluminium melting.

In testing, radiographic and fluoroscopic inspections have had a wider application and "black light" or ultraviolet light inspection has also had some application.

The great expansion in capacity for producing magnesium alloy castings is dealt with by J. C. De Haven. In 1939, the production of sand, permanent mould, and die castings in magnesium alloys in the United States totalled 1·8 million pounds, while the 1944 production was estimated to be 86 million pounds of which 90%

represented sand castings, 7% permanent mould castings and 3% die castings. Millions of incendiary bombs in magnesium were also produced.

A more outstanding development of the wartime magnesium casting production was evident in the quality of the castings made. Besides strict dimensional specifications applied to magnesium aircraft castings, the metal in such castings had to meet high-quality standards, and this necessitated that every step of melting, pouring and heat-treating of castings was kept under rigid control. Improvements in melting techniques for magnesium alloys were also developed which permitted a closer control of the quality of the metal. Gaseous chlorine has been found to be a very effective flux for magnesium alloys, and research has shown that grain refinement equivalent to that obtained by superheating may be obtained by inoculating the melt with carbon. An especially convenient method for bringing the carbon into contact with the melt is in the form of carbon tetrachloride introduced into the fluxing chlorine gas stream. To inhibit oxidation tendencies, very small additions of beryllium have been added successfully to certain die castings and permanent mould castings.

In moulding, synthetic moulding sands, consisting principally of silica sand and bentonite, have had a wide usage during recent years due to their high permeability. Another development has been the application of synthetic resins as core binders in the magnesium foundry. To produce the highest quality castings it has also been found necessary for molten magnesium alloys to be introduced into the mould with a minimum of turbulence, and ingenious gating systems have been evolved which permit bottom pouring and still allow the hottest metal to flow into the risers.

Comparison of high-zinc alloys (2% and 3% zinc) with low zinc alloys (0·5% zinc) have shown that the use of the latter contributes greatly to improved soundness of the castings without a serious sacrifice in resistance to salt water corrosion. Such alloys, however, have only had a limited use.

New Phosphating Plant

Rust-Proofing Plant Installed by Wolseley Motors

THE importance attached to the protection of motor-car bodies and wings against corrosion is indicated by the new £20,000 rust-proofing plant installed by Wolseley Motors, Ltd. Corrosion or rusting of the wings in particular has always been a problem for car owners, and efforts are continually being made by manufacturers to reduce the evil by means of an effective rust-proof coating. The plant installed by Wolseley Motors is designed to provide a phosphate coating on parts treated prior to the application of successive coats of cellulose or synthetic finishers. It is designed on the spray system and embraces compartments to permit six operations through which the parts to be treated are carried suspended from an endless conveyer. All parts of cars given a synthetic finish may be treated, including wings, bonnets, wheels, body, chassis, etc.

The parts treated pass into a special chamber where a succession of hot sprays at high pressure, through stainless steel nozzles, first clean and rinse the surface of the metal, apply a phosphate coating and again rinse and a final finish with a chromic acid rinse, before passing into the drying compartment. From the drying chamber the parts are conveyed to a large tank of enamel into which they are immersed and subsequently conveyed through an oven, operating at high temperature, for baking. The phosphate coating not only retards corrosion but provides excellent surface adhesion for the enamel.

The improved performance of paint and enamel finishes applied to fabricated articles which have been phosphate coated, in relation to untreated articles, is well known, but this plant is noteworthy in that it is one of the largest to be installed in this country, and its use can be regarded as an important step in combating rust and corrosion.

The illustrations show motor car wings entering the new rust proofing plant, passing through one of the spraying chambers, and emerging from the drying chamber.

Staff Changes and Appointments

MR. C. S. GILL has been re-elected for a further term of office as President of the Tees-Side Chamber of Commerce. He is well known in engineering circles, particularly in the North East Coast area, where he is managing director of Davy United Roll Foundry, Ltd., at Billingham, he is also a director of Davy & United Engineering Co., Ltd., of Sheffield, and of Le Tourneau (Great Britain), Ltd. He also holds office in several industrial associations, and is well known for his work as chairman of the British Steel Founders' Association and vice-chairman of the British Roll Makers' Association.

DR. W. STEVEN is joining the Development and Research Department of the Mond Nickel Co., Ltd., on July 1 to take charge of the Ferrous Research Section of their Birmingham Laboratory. As secretary of the Hardenability Sub-Committee he played a prominent part in the preparation of the Hardenability Symposium recently published by the Iron and Steel Institute and summarised in this issue.

MR. R. H. HANCOCK, M.I.P.E., M.I.I.A., has resigned his position as production manager to Simplex Electric Co., Ltd., to become works manager to J. A. Crabtree & Co., Ltd., Walsall.

MR. D. LACY-HULBERT, formerly works director of the subsidiary company, Tubes, Ltd., has been appointed to the Tube Investments Group's Precision Tubes Division as the director of production. MR. W. D. E. ANDREWES has been appointed a director and general manager of the Group's export organisation, T.I. (Export), Ltd., and MR. ARTHUR CHAMBERLAIN has been appointed deputy managing-director of the subsidiary company, Hercules Cycle & Motor Co., Ltd.

MR. P. T. MENZIES has been made a director of I.C.I. Ltd. MR. J. M. MACDONALD has relinquished his secretaryship but remains a director, and MR. N. J. FREEMAN has been appointed secretary.

MR. J. A. AYRES has retired from the position of foundries superintendent, Brightside Foundry and Engineering Co., Ltd., Sheffield, after 52 years' service with that company. He is being retained in a consultative capacity.

MR. J. WOOLMAN, M.Sc. (Local Director of Laboratories, Thomas Firth & John Brown, Ltd.) was elected a member of Council of the Production Engineering Research Association of Great Britain, and Mr. F. H. Rolt, O.B.E., M.I.Mech.E. (Superintendent of Metrology Division, N.P.L.) was nominated by the D.S.I.R. to serve on the Research Committee. Recently there has been a considerable increase in membership applications particularly from firms in the electrical engineering and automobile industries.

Despite restrictions, material shortages, etc., considerable progress has been made in the conversion of "Staveley Lodge," Melton Mowbray, for use as laboratories and headquarters of this Association. One of the main workshops is now completed and the first test machines have been installed.

MR. J. BILSLAND has been appointed managing director of Shotts Iron, Ltd., and MR. J. R. LANE has joined the board but remains as secretary.

MR. FRANK TAYLOR has rejoined International Corrodeless Ltd., as technical advisor and will in future be the editor of the popular *Rovel Metal Finishing Bulletin*.

LIEUT.-COLONEL S. C. GUILLAN, T.D., has been appointed Secretary of the Institute of Metals and editor of its publications. He will take up his duties with effect from July 1, 1947.

MR. DAVID CLEGHORN THOMSON, who has for some months been engaged in the preparation of a report upon training and recruitment in a large section of the steel industry, has now been appointed education officer to Richard Thomas & Baldwins, Ltd.

MR. C. W. STEWART has been appointed foundry manager to C. W. Taylor & Son, Ltd., South Shields, in succession to Mr. J. E. Harle, who has taken up an appointment with the Indian Iron & Steel Co., Ltd., Kulti, Bengal, India.

MR. F. L. TOPHAM is shortly leaving the Stanton Ironworks Co., Ltd., to take up an appointment with Tweedales & Smalley (1920), Ltd., Rochdale.

DR. I. G. SLATER, formerly officer-in-charge, Admiralty Central Metallurgical Laboratory, has been appointed Scientific Adviser, British Admiralty Delegation, Washington, U.S.A.

MR. H. G. GOYNS has resigned his position with Ley's Malleable Castings Co., Ltd., Derby, and will be leaving this country shortly to take up an appointment as general manager of various South African iron and steel companies.

MR. J. A. RICHARDS has resigned from The Crane Foundry Co., Ltd., Wolverhampton, upon his appointment as director and manager of Walter Macfarlane & Co., Ltd., Saracen Foundry, Glasgow.

MR. A. R. PARKES has resigned his position as chief metallurgist, Indian Iron & Steel Co., Ltd., Kulti, Bengal, India, and hopes shortly to return to this country.

WITH the retirement of Mr. Malcolm Dunbar, already noted, the affairs of L. Oertling, Ltd. now pass under the active control of Mr. J. Rock Cooper, B.Com., F.R.S.S., M.R.I., A.M.I.A.A. This involves no change in immediate policy, as Mr. Rock Cooper has directed the manufacturing side for over 10 years, and is well-known to many customers. For the last three years he has been on the Board, and now becomes Chairman of the Company.

THE President (Colonel P. G. J. Gueterbock) and Council of the Institute of Meta.s gave a dinner-party at the Savoy Hotel on 21st May, in honour of the 1947 Institute of Medals May lecturer Sir Wallace Akers director of research of Imperial Chemical Industries, Ltd.

Among those present were: Professor G. Wesley Austin, Mr. W. F. Brazener, Mr. John Cartland, Dr. C. H. Desch, Mr. Arthur Dorman, Mr. Roosevelt Griffiths, Sir William Griffiths, Lieut.-Colonel S. C. Guillan, Dr. J. L. Haughton, Mr. K. Headlam-Morley, the Hon. Richard Lyttelton, Mr. H. S. Tasker, and Professor Dr. A. von Zeerleder.

MICROANALYSIS
CHEMICAL AND PHYSICAL METHODS
APPARATUS METALLURGICAL APPLICATIONS TECHNIQUE

WE have, on former occasions, referred to the need for interchange between international scientists. The article by Mlle. Lacourt, which we publish here, lends point to our arguments. Mlle. Lacourt, who carried on her microchemical researches during most of the war, under great difficulties, was recently able to pay a visit to this country, and her primary concern, in the course of that visit, was to learn as much as possible about the changes that had taken place, in her subject, in the past seven years. She found much that had altered, and much that was new to her, and in her article she deals with some of the points which struck her most forcibly. However, readers of her article will note immediately that the nett result of Mlle. Lacourt's visit was not merely an acquisition and a taking away of information. Mlle. Lacourt had much to relate that was of interest to microchemists here. The experiments in the teaching of microchemistry on which she is embarking have a direct bearing for us here, who are slowly but surely beginning to pay increased attention to this aspect of the subject. With Mlle. Lacourt's conclusions concerning the need for regular personal contacts between the scientists here and those on the Continent we are in strong agreement. The problem is not one affecting microchemists only, of course, although we may be forgiven for applying it in this personal way. But if some broad scheme, in which all sections of the scientific community had their part, were proposed, it would have our support. At present, such interchange is too largely haphazard; and surely scientists should be the last people to leave important factors to chance.

Microchemistry in Great Britain and Belgium

By A. Lacourt

Centre de Microchimie de l'Université de Bruxelles, 50, Ave. F. D. Roosevelt, Brussels

The present article reviews, through the eyes of a Belgian microchemist, the progress that has been made here during the war. It goes on to describe the way in which the training in, and practice of, microchemistry are being developed at the Centre of which the author is the scientific director. Some important conclusions are drawn from this survey of microchemistry in the two countries.

A RECENT short tour of Great Britain, in the course of which I visited a number of chemical laboratories, gave me an opportunity to meet a few of that country's most enthusiastic and convinced microchemists. Included were chemists practising micro-techniques both in applied industrial research and in academic training.

Such meetings, apart from their social and scientific interest, would have increased, had it been in any way necessary, my admiration for some of the best qualities of the British. I mean this very sincerely, since, if these qualities had been absent, it would have been impossible to master in the way they have done the difficult problems set before them in relation to the circumstances of the war. One is astounded, for example, by the remarkable simplicity of some of the solutions suggested by Britain's microchemists for various problems. Their task was often very difficult, they had to deal with chips from enemy weapons and devices of which nothing was known, and of which the only available sample might be a few milligrams or millilitres. New methods of investigation have had to be improvised, just in the same way as new substitutes had to be found to replace materials and drugs that were no longer available during those terrible years of war. Alloys of all kinds, plastics, soporifics, anaesthetics and antiseptics were prepared after thorough experimentation. Microchemistry had its part in all these activities. And now that the problems of peace are arising, the same science is harvesting the fruit of its former war experience.

The Microchemistry Group, with its growing activities, is a body of very dynamic individuals, increasing in numbers every year with the fresh recruits from Universities, colleges, industrial and research laboratories throughout the country. The first members were either self-taught, or were trained by some expert, in techniques that were necessary for their work. This type of training has long since been replaced by regular courses taught

in many of the chemistry schools where the methods are also used in research. Teachers there have achieved outstanding success with their students, just because they believed in the efficiency of the techniques, and consequently microchemistry itself is benefiting from their patient and laborious efforts.

According to circumstances, the field of specialisation varies, sometimes being in quantitative, sometimes in qualitative, organic or inorganic chemistry. Physicochemical methods, on account of their rapidity, and because also of the possibility of completing an estimation of small quantities that could not otherwise be determined by any chemical method, have been developed in a way that is unknown on the Continent.

At present there is increasing realisation in Great Britain that microchemistry is a useful, even an indispensible tool; this will undoubtedly promote a still better organisation of training in the future, and the allotting of more time to such teaching than at present. I hope that the British microchemical movement may serve as an example to my own country.

From my visit I have brought back with me very pleasant memories of the hospitality and friendliness of my colleagues (which is appreciated when one is in a foreign country in these times of restrictions) as well as of their skill. I thank them very much, and hope one day to be able to do my part in turn. The microchemical equipment which I saw impressed me very much by its abundance, perfection and achievement. Great Britain should be proud of her present microchemists, and should rely on them to train her future ones. I hope that further similar meetings may bring us together, so that we may learn from each other of the progress that microchemistry is making in our two countries.

Formation of the Centre de Microchimie de Bruxelles

To encourage such interchange of knowledge, I was asked to give a short account of the experiment that was started in Brussels in the form of the *Centre de Microchimie de l'Université de Bruxelles* in the year 1938. Such an experiment was at that time a very unusual one for Belgium, since it implied active and material collaboration between industry and the University. The expenses of the *Centre* were met in part by a certain number of large industrial firms who were convinced of the efficiency of microchemistry. The Department of Industrial and Scientific Research, section of the National Research Fund (*F.N.R.S.*) which also approved of the venture, took part in the research expenses from the very beginning. A Board consisting of delegates from the different Faculties of Brussels University and from industrial firms administers the Fund. The scientific direction is in my hands, and the actual staff of the *Centre* consists of two assistants with University qualifications, and two unqualified helpers.

The aim of the *Centre de Microchimie* is to promote, by training, teaching and research, the study and practice of microchemistry in Belgium. Several times a year, people from the industrial or official laboratories, together with chemistry students of four or five years standing, may join in a training period, and attend a series of lectures. The training period varies according to the branch chosen—different people have different interests in microchemistry. Its length may be from one to three months, and in addition, students undergoing the normal chemical training have facilities for coming after lectures so that they may carry out some easy microchemical exercises, thus acquainting themselves with the new techniques.

From 1938 to 1941 we trained twenty-seven people in quantitative and qualitative organic and inorganic microchemistry, together with the determination of physical constants. The closing of our University caused a break in our work. Training ceased, and research alone was carried on, up to May, 1944, in special rooms outside the University, loaned to us by Brussels Town Council. Rooms at the University were only returned to us at the beginning of this year (1946) and our apparatus has just been brought back.

Interest in microchemistry is still alive in my country, in spite of these interruptions. New grants are being given by the industrial firms, and a ten-year arrangement has been made to guarantee the life of the *Centre*. Other grants from l'Institut pour l'Encouragement des Recherches Scientifiques dans l'Industrie et l'Agriculture (*I.R.S.I.A.*) help to support the research. On this new financial basis the work is starting afresh, and we have already achieved a training period in November for the benefit of industrial chemists. A research programme in three directions on microchemical subjects is also under way.

Future Plans

The Faculty of Science has recently proposed that, from this year onwards, microchemistry may be an optional course for fourth year students in chemistry or in biochemistry towards their final examination. This has been accepted by the University Board, which means that students may have a training consisting of thirty hours lectures and practice in microchemistry. This will really be too short to give those who have an interest in microchemistry the opportunity to do more than a few very simple experiments. It is obviously insufficient to turn a chemist into a microchemist. Whatever flaws the arrangement may have, however, I must say that it is a very progressive one, and that in making it, Brussels University proves once more to be the most forward in the matter. None of our Universities has, up to the present, organised microchemical teaching. Microchemistry is looked upon as a collection of techniques, very useful to fall back on when research requires it. That is why, in all our Universities, microchemists trained in foreign schools are working, either in the analytical or in the organic chemistry departments, doing analyses. Traditional microchemical training passes on from one to the other. Consequently, this attitude towards microchemistry leaves no room for progress or for broad diffusion. The reason for considering things in this way is, I think, the distrust still felt towards microchemical methods by those who have been taught classical macro chemistry, and who think that reliability does not extend beyond these techniques. The distrust may also in part spring from the fact that these people fear lest the growth of this new gospel may deprive them of some of their own teaching rights. Great Britain has shown that microchemistry has grown far beyond the boundaries of classical University chemistry. She has also shown that it can be taught along with the classical methods without depriving anyone of anything to the benefit of chemical standing. Just in the same way we find, co-existing, physical, bio-organic and analytical chemistry. The emancipation

movement is on its way to the Continent, carrying with it more appreciation for experimental and analytical chemistry and their teaching in Universities. Brussels University is leading the way.

The difficulty of obtaining any special apparatus on the Continent is a very real problem which must be coped with when the time comes to arrange programmes and organised work for these different microchemical sections. During the war years I have already spent some time teaching students to make and to calibrate their own burettes and pipettes. As these instruments are not available at all here, it becomes an indispensible part of the training if the students are to be in a position to use the microchemical knowledge that they have gained from us.

My aim is to let them do as much quantitative analysis as possible, as this is the branch of microchemistry which they will need most later on. Gravimetric analysis although very useful is not highly developed in the students' course, as the technique is almost as lengthy as on the macro scale, so that, apart from training in working with small amounts of material, it does not demonstrate such advantages of microchemistry as economy of time. Titrimetic and colorimetric work are more attractive, and interest the students more often : they are more useful, too, in industrial work. These techniques are able to provide simple and useful exercises for beginners, dealing with inorganic and organic substances. Molecular weight (by Rast's method, ebullioscopic and osmotic methods) melting and boiling points, refractive index, density and solubility are usual exercises, as well as organic micro-preparations and separations which offer an opportunity to become familiar with the abovementioned determinations. A glimpse into chemical microscopy, demonstrations of organic elementary or group determinations, and the inclusion of chromatography give the students an idea of some of the fields within the compass of microchemistry. A different programme is treated each year on account of the short time allowed at present for the course. Since the training of the students must also enable me to judge of their microchemical value, I propose to test them as they proceed with their programme. Each student has to do a different determination, partly on account of the scarcity of reagents and apparatus, but also because of their skill in " cooking " results !

Industrial Training

The course for longer training, as applied to the industrial people, covers organic and inorganic quantitative and qualitative microchemistry and physical constant determination. We pay special attention to titrimetric and colorimetric methods in mineral analysis on the micro scale, and to quantitative organic analysis.

The recent development of physical methods of estimating minute amounts of elements will in future claim our attention. The training available to our people in that field will, however, depend on the possibility of purchasing the required apparatus in the foreign countries where it is manufactured. I rely on my friends in Great Britain to support me and the *Centre de Microchimie de Bruxelles* by impressing on the competent authorities the necessity for their country to produce the equipment required to furnish our needs and to make our training as efficient as possible.

The war has cut us off from your periodicals ; some of these which are new, and contain valuable information about microchemistry, do not reach us. I fear that if we are not helped by a regular *review of microchemical literature* we will be unable to collect full information on this growing and spreading subject.

Chemists and supply houses should be kept informed of progress, so that our great difficulty on the Continent in getting reagents, proper apparatus and equipment for microchemistry, should once and for all come to an end. Finally, it is advisable that microchemical reagents should be supplied *direct* from the makers to the laboratories wanting them—commercial firms are not always favourable nor safe intermediaries where these reagents are concerned.

If I may express a hope, it is that *regular personal contacts* between our *Centre* and British microchemists may be established in some way. An exchange of students from both countries has already been suggested. That is, I think, an excellent basis for future relationships, which on my part will meet all approval, and receive the greatest encouragement. Personal contacts would undoubtedly help us to a better mutual knowledge and to a fruitful common work, and it would kindle the flame of enthusiasm for microchemistry among our people, and be one more foundation for building a better comprehension between our two countries.

Microchemistry Group

May Meeting in Sheffield

AT a joint meeting of the Microchemistry Group of the Society of Public Analysts and Other Analytical Chemists, the Sheffield, South Yorkshire and North Midlands Section of the Royal Institute of Chemistry, and the Sheffield Metallurgical Association, held in the Chemistry Department of Sheffield University, on Friday, May 16th, the following papers were read : The Determination of Carbon, Hydrogen and Nitrogen in Aliphatic Nitro Compounds, by A. E. Heron, A Review of Micro Methods for the Determination of Oxygen in Organic Compounds, by C. E. Spooner, A New Spot-test for the Detection of Sulphites and Sulphur Dioxide, by R. Belcher and G. Ingram, and The Microchemical Analysis of Aluminium-base Alloys, by J. Townend and C. Whalley.

Elementary Analysis

Mr. Heron described modifications of the standard Pregl procedure which had been found to be necessary in analysing aliphatic nitro compounds. When combust-

ing nitromethane in the standard combustion train, with soda-asbestos and phosphorus pentoxide as absorbents, all carbon and hydrogen results were found to be high. By lengthening the heating mortar to 10 cms., thus allowing 6½ cms. of the lead dioxide filling to be heated, results were quite reproducible and close to the theoretical values. The ordinary lead dioxide filling was replaced by granular lead dioxide, while to prevent attack by lead chromate on the silica combustion tubing, this reagent was replaced by 5 cms. of silver wool, and the main filling of the tube consisted of copper oxide only.

At first the usual P_2O_5—glass wool to absorb water was replaced by P_2O_5 mixed with 20–30 mesh glass powder, a more satisfactory filling. Subsequently anhydrone was used as it showed no tendency to retain oxides of nitrogen, a fault of P_2O_5 which has become moist.

A supplementary absorber, consisting of a specially designed bubbler containing sulphuric-chromic acid, and backed by an anhydrone tube, was added between the water and carbon dioxide absorption tubes when dealing with unknown nitro compounds where the NO_2 content might be high. This bubbler removes any excess nitrogen oxides not taken up by the lead dioxide, and is also a help if the compounds burn vigorously.

The micro-Dumas method for nitrogen was improved by the substitution of hydrostatic control on a supply of carbon dioxide from solid carbon dioxide, instead of the usual grooved-tap control. Slight modifications were made, as a result of this change, in the permanent filling of the combustion tube. A modification was also divided, using a larger combustion tube, for 30 mg. samples of volatile compounds of low nitrogen content.

Oxygen Determination

Dr. Spooner's paper divided methods for oxygen determination into indirect or difference methods, which are highly inaccurate, and direct methods, which may themselves be classified as: (*a*) oxidation methods, and (*b*) reduction methods. Solid oxidants such as potassium iodate, or wet oxidants such as chromic-sulphuric acids may be used in the former class. Most of the methods demand a large number of weighings and somewhat involved calculation, in addition to being somewhat indirect. The best oxidant is oxygen used in a closed circuit, but this method calls for very accurate determination of the oxygen volume and the apparatus blank, which may be relatively high.

Reduction methods are in general more satisfactory and more accurate. Reduction may be achieved by hydrogen (ter Meulen's method) or by heated carbon. Hydrogenation methods require the use of a cracking catalyst and a hydrogenation catalyst. There is no need for supplementary determinations, except in the presence of chlorine, but sulphur poisons the catalyst and must be absorbed. Also deposition of carbon affects the cracking catalyst, and the conversion factor is low.

Reduction by carbon produces carbon monoxide, which is swept into iodine pentoxide by a nitrogen stream, giving carbon dioxide and iodine. There is a good conversion factor, and an accuracy of $\pm 0{\cdot}2\%$ on the semi-micro scale is possible if the air blank is reduced by a thorough preliminary sweeping out with nitrogen. The main disadvantage of the method is the high temperature (1,200° C.) required for the reduction.

A Test for Sulphite

Mr. Ingram drew attention to the scarcity of reliable tests for sulphite ion. In the method which he described sulphur dioxide is liberated from the sulphite and passed into acidified ammonium metavanadate solution. The reduced V^{IV} is then treated with ferric chloride which reconverts V^{IV} to V^{V}, and transforms an equivalent amount of ferric ion to ferrous ion. Additions of ammoniacal dimethylglyoxime produces a red coloration which indicates the ferrous ion, and hence sulphite in the original. Alternatively α:α′-dipyridyl or *o*-phenanthroline may be used to indicate the formation of ferrous ion. Sulphide, thiosulphate and nitrite, which interfere, may be readily masked. As little as 4 micrograms of sulphite ion are detectable. The method is being investigated with a view to quantitative application.

Analysis of Aluminium Alloys

Mr. Whalley's paper is the second of a series of which the first dealt with ferrous alloys, being read at the Newcastle meeting of the Group in 1946. A number of the methods appropriate to ferrous alloys were applicable almost directly to aluminium-base alloys, while others required alteration. As before, the aim was to obtain absorptiometric methods which could be applied schematically. The most suitable band for measurement was determined by spectrophotometric methods, but all calibration and application of the methods is by the photoelectric absorptiometer.

The methods for manganese, nickel, copper and titanium are very similar to those applied to ferrous alloys. Manganese is converted by potassium iodate to permanganate, nickel is determined by the oxidised dimethylglyoxime colour, copper by sodium diethyldithiocarbamate, and titanium by thymol.

For iron, thiocyanate was investigated but was not very satisfactory, while neither α:α′-dipyridyl nor *o*-phenanthroline offered sufficient improvement to justify their expense. Nitroso-R salt, by a reaction not yet fully understood, gives a useful blue colour with ferrous iron, obtained by reduction with hydroxylamine in a buffered solution. Interference from copper and nickel is prevented by addition of a small amount of cyanide.

The ferrous-alloy method for silicon appeared, at first to be unsuitable, as the molybdenum blue which is used did not develop in high-silicon-content alloys. However, it was found that if the alloy was first opened with 40% sodium hydroxide instead of 8% hydroxide, the blue colour developed normally in nitric acid solution, and the added salt content did not affect either this or the earlier determinations.

A 10-mg. sample is dissolved in 1 ml. of 40% sodium hydroxide in a gold microbeaker, and the solution is evaporated to half bulk. After addition of 2¼ mls. of 40% nitric acid, the solution is made up to 10 mls., and aliquots for the various determinations are as follows: manganese, 3 mls.; titanium, 1 ml.; copper 0·5 ml.; iron, 2 mls.; silicon, 0·5 ml.; nickel, 0·5 ml.

Reference is made on page 81 of this issue to the recent meeting of the Polarographic Discussion Panel, formed by the Physical Methods Group of the Society of Public Analysts and other analytical chemists. It was the first meeting to be held by this Panel.

High-strength, High-temperature Alloy S-816

By T. Y. Wilson

HIGH-STRENGTH steels for operation in temperature ranges exceeding 600° C. (1,100° F.) have long been in service as furnace parts, internal combustion engine exhaust valves, and wheels and blades for gas turbines. Research to improve these steels has been carried out, and as a result of such work in the United States, the Allegheny Ludlum Steel Corp. has developed a number of alloys which possess unusual strength up to 815° C. (1,500° F.), are responsive to most fabricating operations, and are resistant to burned fuel gases. The alloy of greatest strength has been designated as S-816, while other useful alloys, which are less complex and expensive, have been designated as S-590 and S-588. The high-temperature strength of all these alloys is considerably greater than those of the well-known hot workable austenitic types of corrosion and heat-resisting steels.

It was found that with chromium and nickel properly balanced, the simultaneous presence of molybdenum tungsten and columbium in correct proportions gave superior strength at 650° C. Additions of cobalt also gave a perceptible increase in properties at 650° C. Steels containing 14% chromium were found to have an inadequate oxidation resistance, and, while chromium additions to about 18% could be made without appreciable change in properties, still greater amounts of chromium benefited oxidation resistance at the expense of elevated temperature strength. In a 20% chromium alloy, cobalt provided high-temperature strength which excelled the lower chromium alloys at any temperature in the 650°–815° C. range. The final composition of the steel was approximately 0·4% carbon, 1·5% maximum manganese, 1·0% maximum silicon, 20% chromium, 20% nickel, 4% cobalt, 4% each of tungsten, molybdenum and columbium, and 4% maximum of iron. What originated as a ferrous alloy gained in total alloy content to become a cobalt base alloy containing iron as an impurity held commercially to a 4% maximum. The phases present in S-816 are not specifically known, but it was assumed that the chromium, nickel and cobalt form a solid solution along with some part of the other elements, and that all the alloying elements, except nickel and cobalt, form complex carbides.

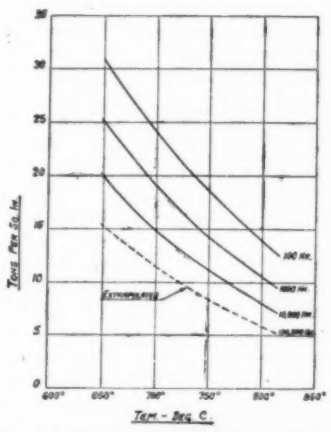


Fig. 1.—Stress rupture curve of heat-treated alloy S-816.

Rapid evaluation of elevated temperature properties were made with the stress-rupture or time-to-rupture test which is intermediate between a short-time tensile test and a long-time creep test. Definite testing procedure was carried cut to give information commensurate with intended applications and their expected life. In Fig. 1 are given typical stress rupture tests of the heat-treated alloy.

The use of S-816 in the as-hot-worked condition gave very erratic results as the properties varied according to the rolling and forging temperatures and the alloy is recommended for use only in a properly heat-treated condition. Heat-treatment was found to consist of a solution treatment at 1,175°–1,260° C., followed by ageing at 730°–815° C. Conditions of intended service govern the selection of an optimum solution treatment. Higher temperatures, up to the fusion point of the intergranular phase, enhanced rupture life, while ductility might drop to about 1% elongation as the result of extreme solution temperature. Ductility was increased with reduced solution temperatures, while rupture time was decreased at low stresses. Rupture stress was quite insensitive to precipitation temperature. Experience, however, showed that a hardness of 26 Rockwell C. or higher after solution treatment at 1,260° C., and ageing at 760° C. was indicative of good rupture properties. Hardness in excess of 34 Rockwell C. indicated cold work after solution treatment and before ageing.

S-816 has been fabricated by all usual processes, although, because of its greater initial strength and better work-hardening rate, ease of fabrication did not generally equal that of the chromium-nickel austenitic stainless steels. The relatively high carbon content, compared to the ordinary stainless steels, made some changes and greater care in welding necessary; nevertheless, arc welding and atomic hydrogen welding can be done regularly under production conditions. Tests showed S-816 to machine best in the fully-aged condition, as in the as-solution treated condition the alloy was most susceptible to work hardening. So far commercial

TABLE I.—STRESS-RUPTURE TESTS FOR CAST S-81

Temperature °C.	Stress-rupture Tons/sq. in.	
	100 Hours	1,000 Hours
650	25·0	20·6
730	17·5	13·0
815	11·6	8·9
870	7·8	5·6
925	5·8	4·45
980	4·7	3·7

From *Materials and Methods*, 1946, Vol. 24, No. 4, pp. 885–890.

production has been limited to billets and bars, although sheet, strip, wire and welded tubing have been produced successfully in experimental quantities. In precision casting good results have been obtained with the alloy when the pouring temperature and mould temperature together were held within rather narrow limits, as these determined cooling rate and consequently dendrite-compound-eutectic size and distribution. As very good results were obtained in the as-cast condition, heat-treatment was generally considered unnecessary. Rupture loads for cast S-816 at 650°–980° C. are given in Table 1, and show that castings will probably find maximum utilisation at temperatures higher than appears to be practicable for wrought materials.

Iron Powder Manufacture in Germany

THE manufacture and use of metal powders generally in Germany has been already dealt with in earlier B.I.O.S. reports. Two recent ones, No. 860, by an Australian Technical Mission, and No. 908 by an English team, relate solely to iron powder manufacture and some of its uses. The works visited by both groups were the Düsseldörfer Eisenhüttenges. and the Deutsche Eisenwerke. The English team included one or two others in their itinerary. There is thus a certain amount of duplication in the reports, but only the Australians include notes on diamond impregnated tool making at Dusseldorf.

Here the Hametag method appears to be the only one used for production of iron powder. This is referred to several times in the symposium on metal powders of the American Society of Metals (1942) as owned by the Hartstoff Metal Co. of Germany and covered by U.S. patents Nos. 1832868, 1930684, 1932741. There is thus little need to describe it in detail. Briefly it is a mechanical process in which iron wire is cut into small pieces and ground to powder in a special type of Hametag mill. This is fitted with a gas compressor whereby coke oven gas is forced into the mill to prevent dust explosions and control particle size. At Dusseldorf there were 20 of these mills, each of 5-ton month capacity; but at another works—of the Reichwerke A.G.—it was understood 300 Hametag mills were installed during the war for iron powder to be used in projectile driving bands. The powder is now chiefly used for bearings and other machine parts after having been pressed and sintered to about 25% porosity. Pressing is done in the usual way, but prior to sintering. Hot pressing is not used. Several types of presses were seen in the German works visited, including the smaller Hahn & Kolb of 60 tons, and larger ones of 300-400 tons. Sintering is either batch or continuous, and four different types of furnace are employed, gas-fired or electric. The furnace atmosphere may be either hydrogen or carbon monoxide.

There is nothing very new in the methods described for production of diamond impregnated tools, such as laps, glass and porcelain boring and cutting tools, core drills, etc. The chief method, in fact, is the Belgian Neven process, patents for which are owned by Boart Products, Ltd., London. About 30% diamond powder of specified particle size or distribution is mixed with iron powder of specified fineness, and the mixture hot pressed and sintered under 1 ton/cm² and about 1,000° C. Some details are given of moulds and shaping and use of steel backing plates.

At the Deutsche Eisenwerke, Mulheim, the D.P.G. or Degussa process is used (Deutsche Gold- u. Silberscheide Anstalt). In this a Demag granulating machine provides a powerful funnel-shaped water jet whereby molten steel, after being decarburised in a converter and then again carburised by addition of anthracite, is atomised and further disintegrated by the blades or knives attached to a heavy disc rotating at high speed. After drying and sieving the powder is packed in trays and placed in steel circular pots. On top of each charge is a tray of crushed anthracite. The pots are closed and loamed up, and heated to 960° for ten hours, whereby the oxide skin and the carbon content are reduced. The material then has to be reground and again sieved. Average final yield is about 70% of converter metal.

The English group also visited the two works of the Schwelmer Eisenwerke A.G. at Schwelm and Krebsoge, and that of the V.D.M. Sintermetallwerke, Neurod. At the two former, though closed, they were able to collect a few details from Dr. Schwalbe; but full information had been already given to earlier investigators, together with copies of a paper read by Dr. Schwalbe at a Powder Metallurgy Conference in Berlin. The same author proposes to write a further report on developments with sinter steel. Various types of powder are used by the Schwelmer company: that made by oxide reduction gave the highest strength before sintering, whereas maximum strength in finished product was found in those made from mechanically prepared powder. The usual practice was to blend the different kinds of powder, and anneal in hydrogen atmosphere, at 700–1,000° C., after which further crushing and disintegrating was generally needed.

For sintering, the products were first preheated in hydrogen-filled containers in low temp. batch furnaces to remove lubricating oil used in pressing; and then, packed in trays, put into inclinable furnaces—to facilitate tray movement—where they were heated up to 1,100° C. for iron and 1,200° C. for sinter steel. In this latter case the atmosphere was purified nitrogen plus 10% hydrogen.

A feature of interest at the V.D.M. works—also visited by earlier groups—was the variety of mechanical presses, including (*a*) vertical cam-operated press by Maschinenfab-Weingarten; (*b*) multiple die press by Henning & Marten, Leipzig; and (*c*) multiple die rotary presses by Friedr. Horn Maschinenfab., Worms a. Rhein.

Magnetic Suspensions for Obtaining Magnetodefectograms

A MAGNETODEFECTOGRAM is a permanent record of a defect in a steel part. It is in the form of a transparent film produced on the article itself by the drying of a special type of magnetic suspension. The film, carrying a magnetic powder trace of the defect may be removed from the artice and preserved.

Sveshnikov, in the Russian journal *Zavodskaya Laboratoriya*[1] has recently described the results of a comparison of two forms of magnetic suspensions which may be used for this purpose.

The normal practice in Russia appears to use a suspension of crocus powder in a solution of celluloid in acetone or amyl acetate. One of the

1 Sveshnikov, D. A., *Zavod. Lab.*, 1945, **11**, 186.

following composition was used in the tests:

Amyl acetate	700 ml.
Ethyl alcohol	300 ml.
Celluloid	25 g.
Crocus	25 g.

This was compared with a collodion solution, recommended in the first place on the ground that it did not require the use of materials in short supply (acetone or amyl acetate); the latter had the following composition:

Collodion	500–600 ml.
Ethyl alcohol ..	500–400 ml.
Crocus	25–35 g.

The two suspensions gave identical defectograms but the collodion solution was superior in respect of the transparency of the film. Moreover, it dried more quickly than the amyl acetate solution and, consequently, the article did not have to be left so long in the field of the electromagnet. This was an important point since the deposit tends to become diffused as the time is lengthened. A disadvantage of the collodion suspension was that during the final drying of the film removed from the article, wrinkling occurred. However, it was found possible to avoid this by placing thin paper on the film while wet and sticking the paper in a cardboard frame. In drying the paper stretched somewhat and a high quality magnetodefectogram was obtained.

Permanent Mould Grey Iron Castings

By E. C. Hoenicke

ALTHOUGH many operations in sand casting are difficult to mechanise, the number of machines available to the foundry is steadily increasing. Such machines as the sandslinger, the jolt-rollover, the squeezer and others, perform some one or occasionally several of the operations of making the mould from sand or other materials. Progress has also been made in mechanising the casting process itself, and in the United States a machine has been perfected and used which produces grey iron castings in volume in mechanically operated metal moulds without the application of pressure.

The permanent mould machine consists of 12 hollow arms, mounted in circular fashion and so connected as to rotate about a central pipe which acts as a hub. At the extreme ends of each arm are inner and outer heads. One half of a mould is attached to the outer head and the other half is fastened to the inner head, which is movable, being actuated by air cylinders to close, hold and open the moulds. Cooling air passes over both halves of the mould through the hollow arms and into the central pipe, where it is exhausted. The mould is filled at 1,315°–1,370° C. from a rotatable ladle as the machine slowly revolves. By the time the fifth arm passes the operator—40–80 seconds—the metal in the first mould has solidified and cooled, and the mould is opened automatically by cams and the casting, cooled to 370°–425° C., is removed from the mould. The remainder of the machines cycle is concerned with the preparation of the mould for the next pouring. The mould first passes in front of a jet of air which cleans the cavity of any loose particles of metal, then it moves under a hood where acetylene burners deposit a coating of lamp black over the faces of both halves of the mould, cores, if any, are inserted, and the mould closes automatically and comes to the first position again, where another casting is poured.

TABLE I.—PHYSICAL PROPERTIES OF GREY IRON CAST IN PERMANENT MOULDS

Section	0·5 in.	0·875 in.	1·2 in.	2 in.
Tensile strength, tons/sq. in.	23·3	15·2	14·3	10·1
Modulus of elasticity, lb /sq. in. × 10^6 ..	19·53	17·57	13·60	11·98
Brinell hardness ..	197	187	180	170
Compressive strength tons/sq. in.	55·6	50·1	53·5	44·5
Torsion, yield shear, tons/sq. in.	—	10·4	8·6	9·1
Torsion, rupture shear, tons/sq. in.	—	19·5	18/8	16·3
Torsion, modulus, lb./sq. in. × 10^6 ..	—	7·435	6·747	6·31
Transverse breaking load, lb.	606	1,665	2,670	8,200
Transverse deflection, in.	0·178	0·166	0·283	0·240
Modulus of rupture, tons/sq. in.	44·2	33·85	36·6	28·0
Bending modulus, lb./sq. in. × 10^6 ..	19·6	16·94	14·38	14·87
Endurance limit, tons/ sq. in. ..	14·6	8·95	8·70	6·05
Heat-treated tensile strength, tons/sq. in.	36·8	23·2	17·3	14·4
Heat-treated tensile modulus, lb./sq. in.	19·2	17·4	13·36	10·95
Growth increase in volume % per cycle	0·133	0·170	0·180	0·330

The speed at which the machine travels is set at such a rate that the moulds, which have been preheated to about 370° C., will not cool below 315°–425° C. during the casting operation. Because of the preheating of the moulds, any excessive chilling of the castings is avoided. A rapid and uniform withdrawal of heat is necessary so that the casting can be removed from the mould in about 1 minute of the time of pouring. Such cooling is also necessary to obtain a uniform distribution of graphite in the casting.

For permanent mould castings a cast iron containing 3·4–3·6% carbon, 2·4–2·6% silicon, 0·7–0·9% manganese, 0·30% maximum phosphorus and 0·1% maximum sulphur is suitable. The physical properties of such an iron, after being cast in permanent moulds, are given in Table I. The tensile strength and deflection are much greater than for irons of similar composition cast in the usual way. The absence of surface hardness and scale and the fine-grained, uniform structure of permanent mould grey iron castings permit easier machining, higher cutting speeds and faster feeds. Growth and distortion are held to a minimum by the uniformity of the metal and the fine-grained structure permits of good surface finishing. Permanent mould castings also possess a porous-free structure with sufficient density to retain liquids and gases under pressure in hydraulic and refrigerating units. In many cases, such castings have replaced brass and bronze satisfactorily.

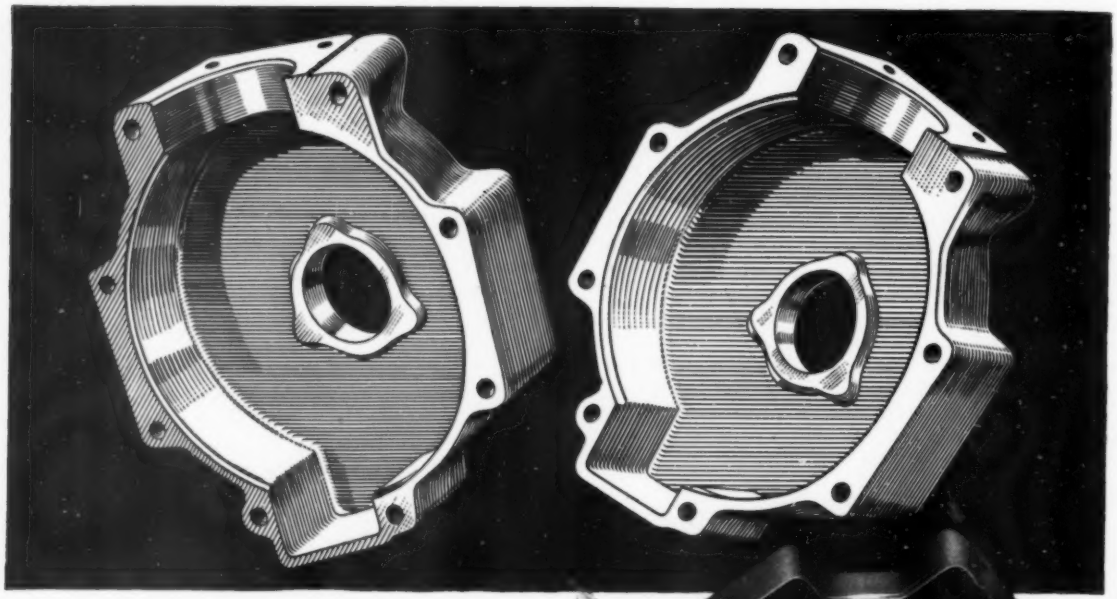
The moulds are made of heat-resisting cast iron and have a life of 3,000–10,000 casts if properly designed. As the moulds are not permeable, sufficient venting must be provided through core prints or in some other ways when cores are present. All twelve of the moulds used on the machine can be different, provided that they have the same cooling rate if used at the same time. The design of castings produced by the permanent mould process is basically the same as for other types of moulding.

From *Materials and Metals*, 1946, Vol. 24, No. 4, pp. 901–904.

Development of New 2,000 h.p. Gas Turbine

AN experimental 2,000 h.p. gas turbine generator set that weighs only 19 lb. per h.p. and starts in one and a half minutes or less has been

From *Bradley's Magazine*.



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In a paper prepared for presentation before the annual meeting of the American Society of Mechanical Engineers on December 5th, the existence of the new gas turbine generator set was disclosed. Details of the 2,000 h.p. unit were set forth by Thomas J. Putz, manager of the gas and locomotive turbine section, steam division, Westinghouse Electric Corp., South Philadelphia.

Burning No. 6 (bunker "C") fuel oil to compensate economically for an expected thermal efficiency of its simple open cycle of 20% at full load, the gas turbine generator set operates at a top temperature of 1,350° F.—the maximum practical temperature using currently available materials without resort to cooling. The simplest type of open cycle, consisting of only a compressor, combustor and turbine is employed in order that operating experience on these major components may be most quickly acquired.

Grain-Growth Inhibitors in Steel

By J. W. Halley

"FINE grained" steels have been standard products for many years and the properties, response to heat treatment, and the deoxidation practice necessary to produce such steels, have been the subject of numerous investigations. It has been shown that a substantial quantity of aluminium is necessary to produce this type of steel, and it has been indicated that titanium and zirconium produce a similar result. As most of the work on grain size has divided steels into two broad classifications based upon McQuaid and Ehn's original carburising test at 925° C., steel coarsened at this temperature is considered coarse grained and, if it remained fine, it is considered fine grained. Quantitative data concerning how much a certain amount of aluminium raised the coarsening temperature and affected the properties, all other factors being constant, are very meagre, and similar information regarding titanium and zirconium is practically non-existent. This investigation was therefore undertaken to study the effects of those grain-growth inhibitors.

The temperature at which a steel coarsens can be determined by heating a number of samples to successively higher temperatures and cooling at a rate to outline the austenitic grains so that coarsening can be followed. In the investigation this procedure was greatly simplified by heating samples in a gradient temperature furnace. Low-carbon samples were oil-quenched from the furnace, sectioned longitudinally, polished, and etched in nital when the temperature range, during which coarsening occurs, showed very clearly. A perfect correlation was found between the McQuaid-Ehn tests and the gradient furnace tests heated for four hours. Steels that had not started to coarsen after four hours at 925° C. were fine grained in the McQuaid-Ehn tests; steels that had started to coarsen below 925° C. but were not completely coarsened at this temperature, had a mixed grain size in the McQuaid-Ehn test; and steels that were completely coarsened below 925° C. were coarse grained in the McQuaid-Ehn test.

The effect of individual elements on grain coarsening was investigated by adding increasing amounts of the elements to a series of ingots of an open-hearth heat. Additions of ¼, ½, 1, 2 and 4 lb. per ton were made to successive ingots and samples were cut from the middle of each ingot and forged to 1 in. rounds, which were used for grain coarsening, tensile tests and Izod impact tests. Steels of about 0·30% carbon, 0·80% manganese and 0·25% silicon were used for all of the series. In the aluminium series, aluminium ranged from 0·001 to 0·169% acid-soluble aluminium; in the titanium series from 0·003 to 0·170% titanium; and in zirconium series from 0·009 to 0·134% zirconium. Before grain-coarsening or physical tests were made all samples were normalised at 870° C. The results of the grain-coarsening tests for the three elements are plotted in Fig. 1.

The three elements were found to differ in type as well as in degree of grain-inhibiting tendency. Aluminium was most effective as a grain growth inhibitor when 0·028%, as acid-soluble aluminium, was present. It was difficult to reconcile this critical amount with any theory involving grain-growth inhibiting by aluminium oxide. The simple relation found between titanium content and coarsening temperature indicated that the mechanism of grain-growth inhibiting by titanium was much less complex than that of aluminium. This relationship was also perfectly compatible with that of grain-growth inhibiting by titanium carbide. Zirconium was less effective than either aluminium or titanium as a grain refiner. The improvement obtained in notched impact resistance at temperatures ranging from 25° to —73° C. by these elements was considered more a direct alloying effect than the result of grain refinement. As grain refinement does improve the notched impact resistance it was difficult to distinguish alloy and grain refining effects. Considering the alloying effects alone, aluminium and zirconium were found to be beneficial to low temperature impact resistance and titanium was detrimental.

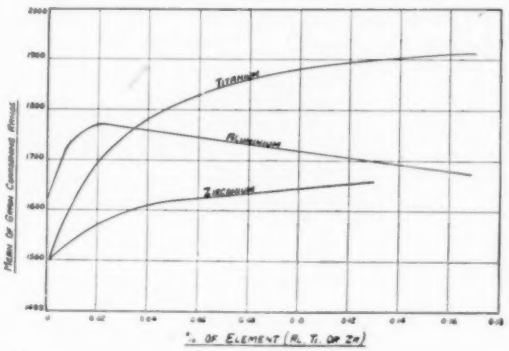

Fig. 1.—Effect of elements on grain coarsening.

From *Metals Technology*, 1946, Vol. 13, No. 4, and *A.I.M.M.E. Technical Public.* No. 2030, pp. 1-11.

Determination of Small Amounts of Copper in Metallic Aluminium by Means of Internal Electrolysis

THE internal electrolysis method of Blok, Shumilova and Gorskaya[1] for determining copper in aluminium alloys has been investigated further by Suvorovskaya,[2] who finds that it is suitable for copper contents from 5% to 0·5%, but not below the latter figure. It appears impossible to use a larger sample weight than 5 g., because of crystallisation of salts from the solution, unless a preliminary separation of copper is carried out. The details of the new method are as follows:—

A suitable weight (5 to 10 g.) of sample is treated with 50–80 ml. of 20% sodium hydroxide solution, and after addition of 15–20 ml. of 10% sodium sulphide solution to ensure complete precipitation, the solution is left to stand until the supernatant liquid is quite clear. The solution is then filtered and the insoluble matter is washed and returned with the filter paper to the flask used for the original attack. It is there dissolved by heating on a sand-bath with 30 ml. of nitric acid (1 : 1). The solution is filtered, ammonia solution is added until a permanent cloudiness appears, 4 ml. of sulphuric acid (1 : 1) are introduced, and then the pair of electrodes, joined together outside the solution, is immersed.

Numerous experiments showed that the electrolysis takes place much more intensively and that copper is completely deposited, if a saturated solution of sodium chloride is added to the liquid.

With low copper contents the iron in the sample does not usually exceed 0·1%. It is unnecessary to add any reagent to give a complex with iron or to add any special reducing agent since iron is reduced during the passage of the current.

The material of the anode, the state of its surface, and the temperature of the electrolyte are important matters.

The anode used is of metallic aluminium, free from copper, in the form of a plate 48 × 15 × 0·5 mm. Before use it should be rubbed with emery and washed with distilled water. After being in operation for some time the surface becomes rough and cementation of copper occurs. This may happen so actively that the whole surface becomes covered with a reddish layer of copper. To avoid this effect it is necessary that the surface be fairly smooth. Electrolysis takes place at room temperature but more rapidly at 70–80° C. Heating above 80° C., however, must be avoided, since copper becomes partly oxidised.

Some results obtained with this method in comparison with the external electrolysis method (figures for this in parenthesis) are: 0·36% (0·36), 0·22% (0·23), 0·22% (0·22), 0·30% (0·30), 0·12% (0·11), 0·093% (0·09), 0·07% (0·07) and 0·045% (0·05).

1 *Zavod. Lab.*, 1941, **10**, 28; METALLURGIA, 1944, **30**, 274.
2 *Zavod. Lab.*, 1945, **11**, 474.

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